NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

EVALUATION OF HELICOPTER PILOT'S ATTITUDE CONTROL USING A SIMULATED HEAD-UP DISPLAY IN A SIMULATED HELICOPTER COCKPIT

by

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June 1982

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Evaluation of Helicopter Pilot's Attitude Control Using a Simulated Head-Up Display in a Simulated Helicopter Cockpit		5. TYPE OF REPORT & PERIOD COVERED Master's thesis; June 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael C. Stichter		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1982
		13. NUMBER OF PAGES 57
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopter Head-Up Display
Helicopter Simulation
Head-Up Display Flight Evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Evaluation of Helicopter Pilot's Attitude Control Using a Simulated Head-Up Display in a Simulated Helicopter Cockpit

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

As demands on the aviator's aeronautical, technical, and tactical skills increase, so must the employment of advanced cockpit design concepts. Advanced systems make for a reduced crew workload and a safer, more proficient mission capable aircraft. Six designated helicopter pilots (Navy, Marine Corps and Army) were evaluated on their ability to fly a simulated instrument flight regime using only a head-up display as an attitude reference. Flight and control simulation was obtained through the construction of a generic helicopter cockpit, with dynamic gage indications generated by an analog computer. Two head-up display flights were flown with the display in the 12 o'clock and 2 o'clock positions. Their results were compared to an initial flight using cockpit instrumentation only. All three flights were identical profiles. Pilot performance was recorded graphically with strip charts and reduced into three "performance zones".
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ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to the following technicians; Ron Ramaker, Ted Dunton, Ray Garcia, Glenn Middleton and Bob Besel. Without their skills and constructive criticism, the conception and building of the helicopter and head-up display simulator would not have been possible. The guidance, technical assistance, patience and motivation received from Professor Donald M. Layton was greatfully appreciated. Finally, the author adds a very special thank-you to his wife, Marcia, for her unyielding support and understanding during this entire project.

I. INTRODUCTION

> There are two situations in which rapid assimulation of the flight situation is especially necessary. The first is the higher-than-usual workload situation in which flight conditions are changing, communication demand is high (combat), etc. The second is the very low workload situation that is interrupted by an unexpected event (emergency). In both cases, the need is for a display set from which the current situation can quickly and easily be assessed at a glance. This display set must also furnish appropriate information for all intermediate levels of decision and control functions.[1]

In the past twenty years a tremendous diversity in the mission of the helicopter has evolved. The helicopter's primary mission is no longer search and rescue (SAR) (although carrier flight operations mandate an airborne SAR helicopter) but has expanded into the following specializations: verticle replenishment, anti-mine warfare, anti-submarine warfare, over-the-horizon targeting (anti-ship warfare), anti-tank warfare and general troop projection and support.

Concurrent with each new mission employment or increase in sensor/weapon sophistication, the aeronautical, technical and tactical skills of the aviator must follow the same evolutionary advance in order to insure effective utilization of the aircraft in its new role or configuration. Of equal

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[1] Baty, D.L. and Watkins, M.L., <u>An Advanced Cockpit Instrumentation System: The Coordinated Cockpit Display</u>, p. 2. National Aeronautics and Space Administration, July 1979.

importance, parallel development and employment of new, hybrid/advanced aircraft monitoring systems, both analytical and tactical, must be incorporated. It is in this development and use of advanced helicopter display systems that the armed forces have discovered themselves falling behind.

Tremendous technological advancements have been made in the field of aircraft cockpit design and system parameter analysis with corresponding displays. For years tactical and commercial aircraft have enjoyed the luxury of digital read-out, bar-gages, cathode ray tube displays (CRT), and head-up displays (HUD). Their systems are computer monitored and have the ability to alert the crew to an impending malfunction prior to it becoming an emergency condition. These systems make for a reduced crew workload and a safer, more proficient mission capable aircraft.

Unfortunately, in the Armed Forces, the distribution and incorporation of advanced cockpit design has been limited to tactical attack and fighter aircraft. The helicopter pilot has been left to do his best with a clutter of dials, gages, indicators, lights, audio tones and toggle switches, and at the same time is expected to respond to increasing demands in an ever complicating mission environment.

Because the helicopter's mission has increased in its complexity, the requirement for an advanced display system can probably be best fulfilled by the implementation of a cockpit head-up display. With the projection of computer

generated symbology onto a fixed plane, i.e., the windscreen, the helicopter pilot can be freed from spending much of his scan time "in" the cockpit.

Oppositions to cockpit change are economic and operational realities, resulting in that substantial changes in cockpit instrumentation cannot be imposed within a short period of time. The proven system of a head-up display would represent a quick transition and sound solution to the problem. Acceptance and successful use of a new display becomes as important as the realization that the display is necessary.

Since helicopter pilots are normally not trained in the use of a head-up display, it was necessary to develop an evaluation technique which would incorporate the unique flight control system of a helicopter and test their ability to fly using this type of display. A generic simulated helicopter cockpit was constructed. Head-up display symbology and cockpit presentation position were determined.

Experienced U.S. Navy, Marine Corps, and Army helicopter pilots were evaluated on their ability to use a simulated head-up display in a simulated instrument flight condition. Their performance was recorded graphically and reduced into "performance zones". These zones represented a percentage of total flight time at various degrees of pilot performance. Zone one was designated the acceptable flight control zone and the time in this zone was averaged for each pilot, plotted, and represented the overall results of the evaluation.

II. EVALUATION TECHNIQUES

A. SUMMARY

The evaluation facility was an environment that would challenge the pilot's aeronautical skills, but leave him at ease; through the use of familiar controls and instrumentation. Flight simulation was kept simple. It consisted of the helicopter being flown straight and level at constant airspeed with analog computer generated inputs to the instrumentation. These inputs represented vertical, horizontal, and lateral wind gusts. The helicopter cockpit was of generic design. Collective, cyclic, and rudder pedal forces were very similar to those encountered in an actual helicopter. The cockpit instrumentation included a simulated attitude indicator, side-slip indicator, vertical speed indicator, and an airspeed indicator. The flight controls and analog computer inputs were summed and drove the indicators on the instrumentation. In addition, vertical speed and airspeed indicators were coupled, to give proper feedback to each other, for a given control input. The head-up display assembly was separated from the cockpit due to its size. However, by the use of a video camera and monitor system, the display was transmitted to and presented in the cockpit. The head-up display included an attitude indicator, vertical speed indicator, airspeed indicator, and s side-slip indicator. Control and analog computer inputs to the head-up display

were identical to those in the cockpit. The pilot's ability to maintain balanced flight, level attitude and constant altitude was recorded on a strip chart. His performance was evaluated by measuring the distance and time he was deflected from an imaginary horizontal line drawn down the center of the strip chart plot for each of the three flights. A comparison of his performance using the head-up display versus the instruments was graphically plotted.

B. COCKPIT DESIGN

A helicopter simulator or previously constructed helicopter mock-up was not available for this study. Therefore, a helicopter simulator had to be constructed. A generic design was the best route to follow, since pilots from different helicopter communities were to be evaluated (Figure 1). The Aeronautical Engineering Department had a large inventory of parts salvaged from various trainers and aircraft. The rudder pedals, complete with their supports, came from a jet link trainer, the cyclic was a jet, backseat control stick, and the collective was a side-mounted radar slew stick (Figure 2). Four simulated instruments were designed for the cockpit. Yaw and pitch were represented on an X/Y Dumount twin-axis oscilloscope. The face of the display was painted with horizontal lines, marking degrees of pitch. Airspeed was presented through the use of a D.C. microampmeter. The input voltage to this meter had to be dropped across a 20K Ohm, linear, center-tapped resistor in order to have appropriate

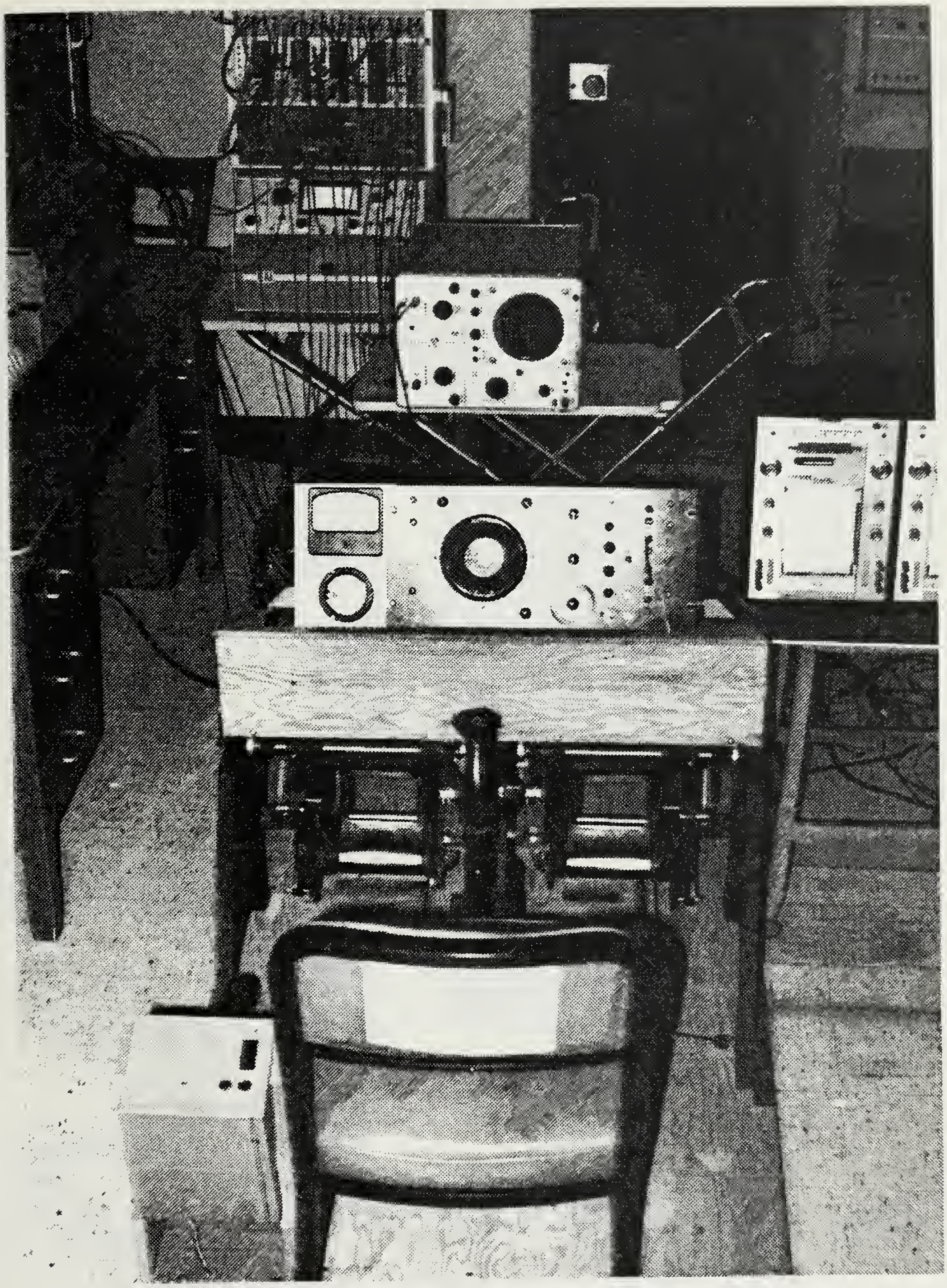


Figure 1. Generic simulated helicopter cockpit

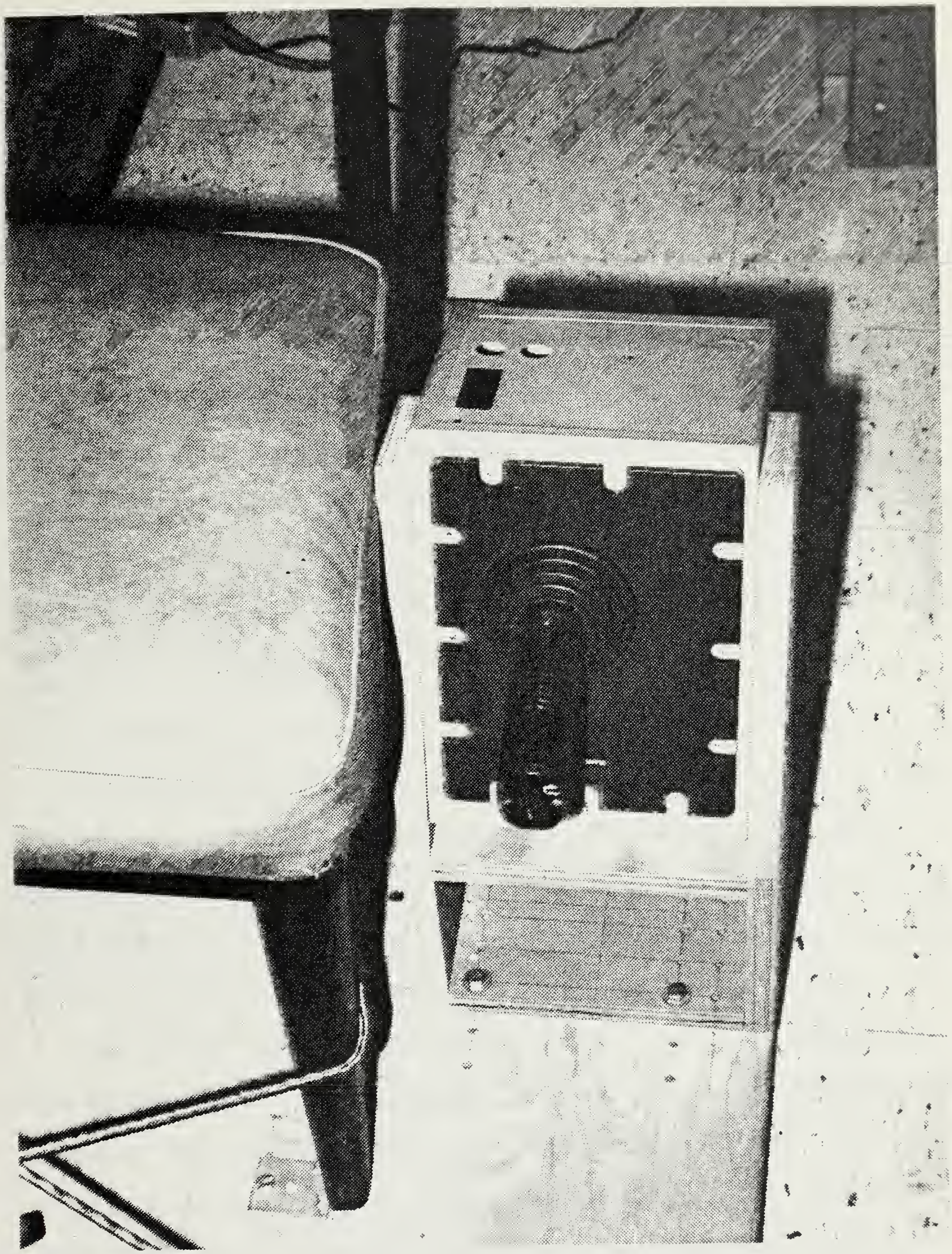


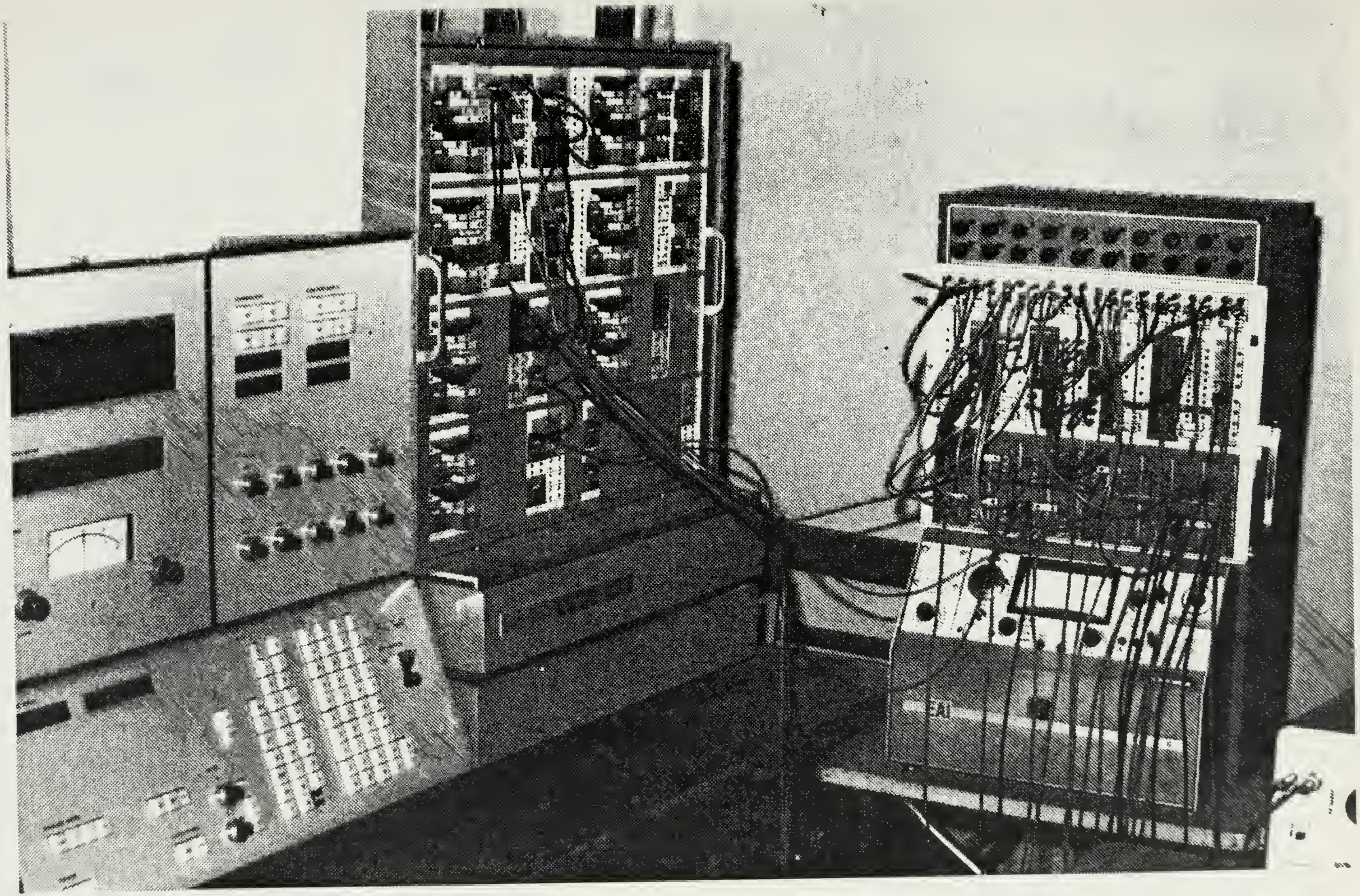
Figure 2. Collective assembly

needle movement for corresponding control inputs. A D.C. voltmeter made an excellent vertical speed indicator. However, it had to be biased in order for the zero needle position to remain horizontal. Finally, the slide-slip indicator was a Tektronic, type 504 oscilloscope. By focusing the blip into a 5/8 inch circle and having it move along the horizontal axis, a "needle-ball" indicator was simulated. Elastic bungees were attached to the cyclic, providing stick stability and force. Resistance was inherent in the collective due to its internal centering assembly. The rudder pedals had a toe brake system incorporated, regulated by a pair of spring dampers. This tension in the braking system was acceptable for rudder tension and therefore the rudders were driven off the braking system.

C. ELECTRICAL CIRCUITS

An EAI (TR-20) analog computer controlled the electrical circuits. The analog computer was programmed to generate unsteady, continuous, voltage signals to the cokcpit instrumentation and the head-up display (Figure 3). These programmed signals imulated the unsteady (gusty) wind conditions.

Two input signals were programmed. Each was sinusoidal and consequently used identical wiring on the analog computer. However, the potentiometer settings were different so that the sine waves varied in phase and amplitude. By summing these two waves, an irregular signal was produced and used as the function for the side-slip indicator (Figures 4 and 5).



Figre 3. TR-20 EAI analog computer assembly

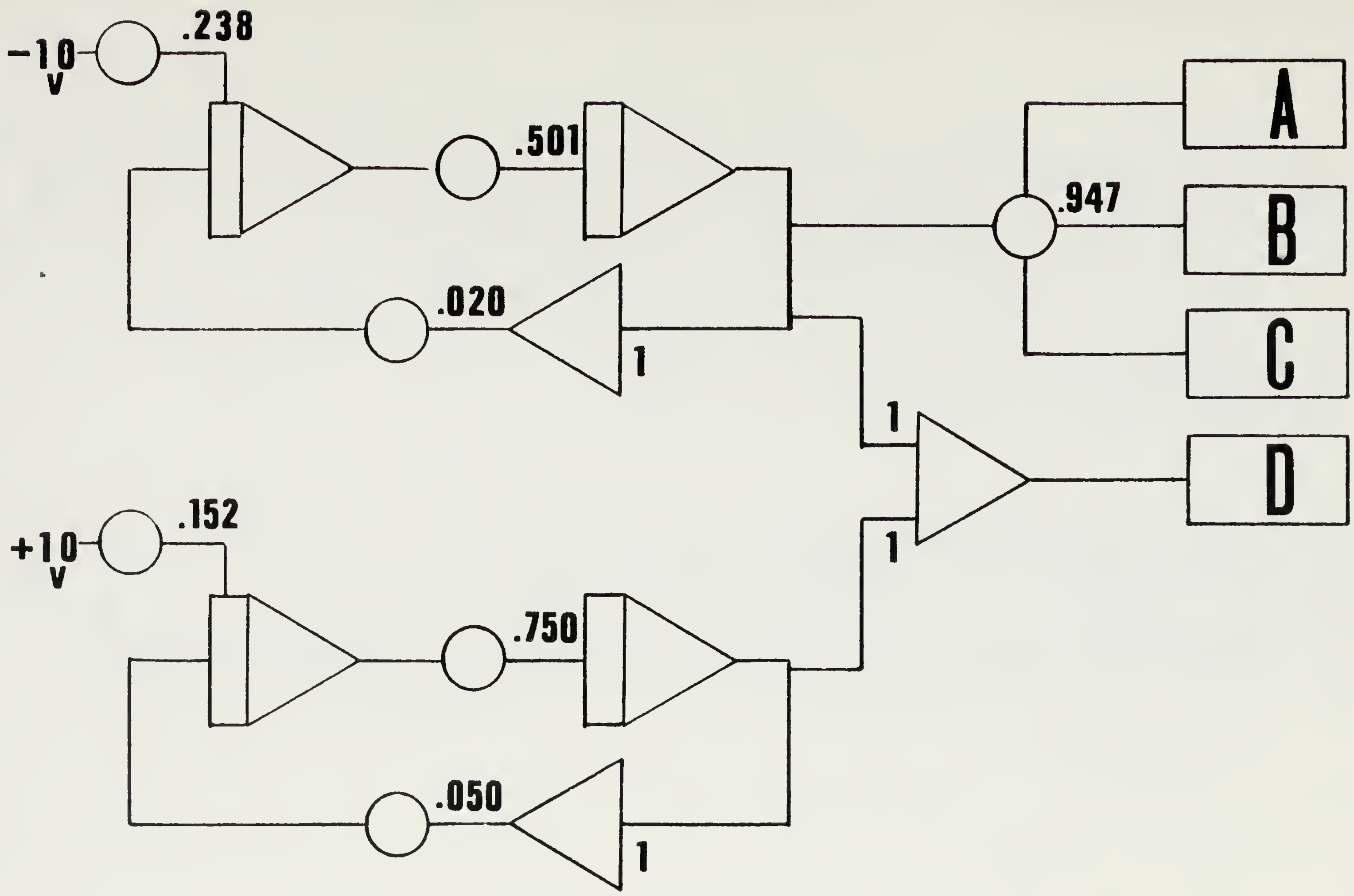


Figure 4. Logic diagram for the analog functional voltage inputs

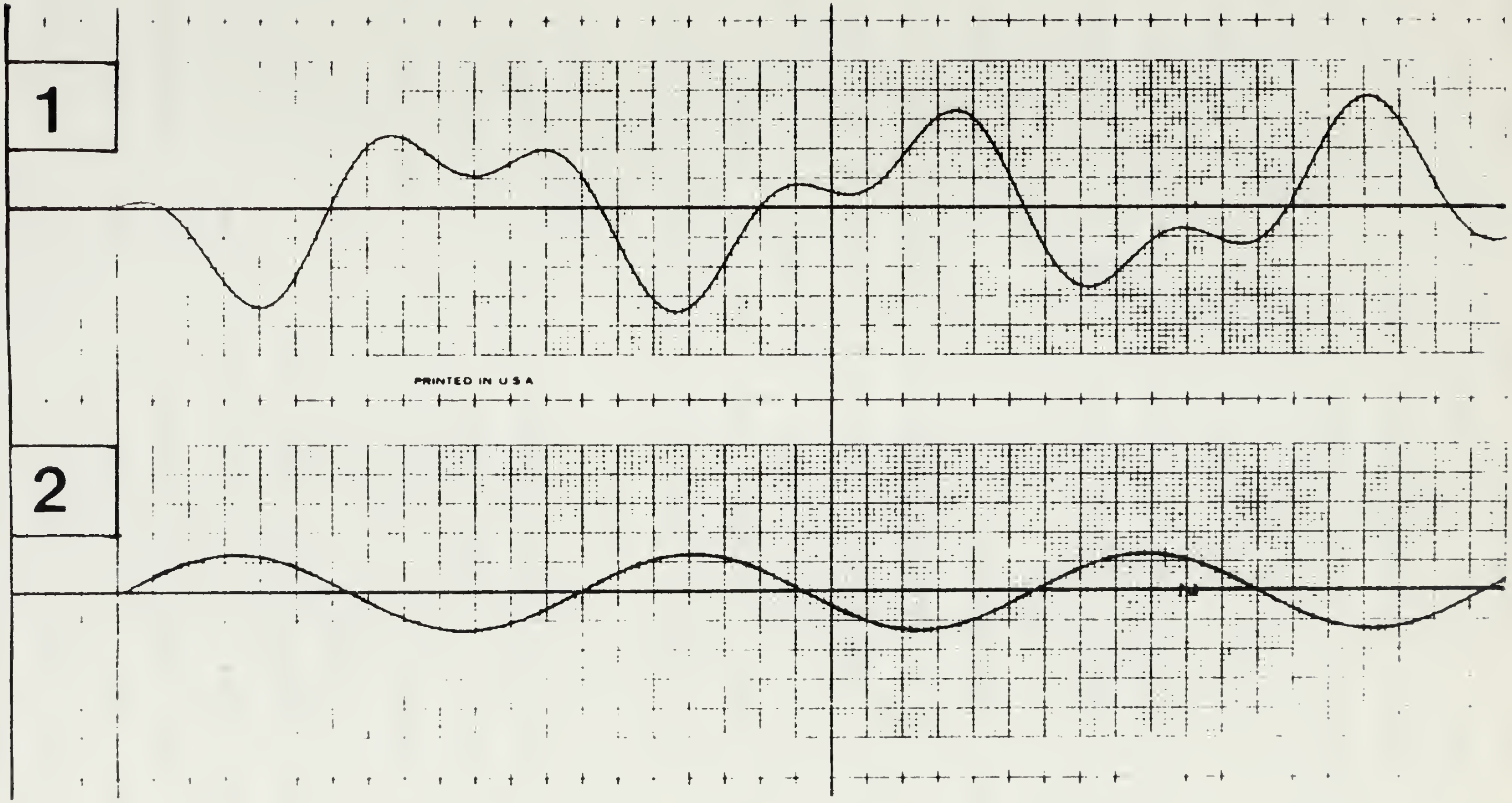


Figure 5. Side-slip (1) and Vertical Speed (2) Indicator functional voltage input plots

A single sine wave was used as the input voltage function to the vertical speed indicator and the X/Y oscilloscope. Voltage functions to each head-up display element were identical to those of its corresponding instrument. These uncomplicated functions were challenging to the pilots without becoming over-taxing (Figure 6).

On each mechanical control was mounted a center-tap potentiometer (6K Ohm). This assembly allowed a percentage of a constant input voltage to the control to be summed through the analog computer with the voltage functions discussed earlier. The resultant voltage was sent to the instruments and displays to give a realistic indication of flight, (Figures 7-10). Also, this summation was sent to the strip chart recorders and from these graphical plots, a measurement of the pilot's performance was made (Figure 11).

D. HEAD-UP DISPLAY

The head-up display consisted of three type 504 Tektronic oscilloscopes and one X/Y plotter table. A face plate was mounted in front of the plotter and oscilloscope assembly in order to hide the wiring and provide continuity to the display (Figure 12). A video camera photographed the display's movement and transmitted the video to an eight inch black and white monitor mounted in the cockpit. All electrical signals to the head-up display were identical to their respective indicators in the cockpit. Guidelines were taped on the monitor's screen to define the position of center ball, level

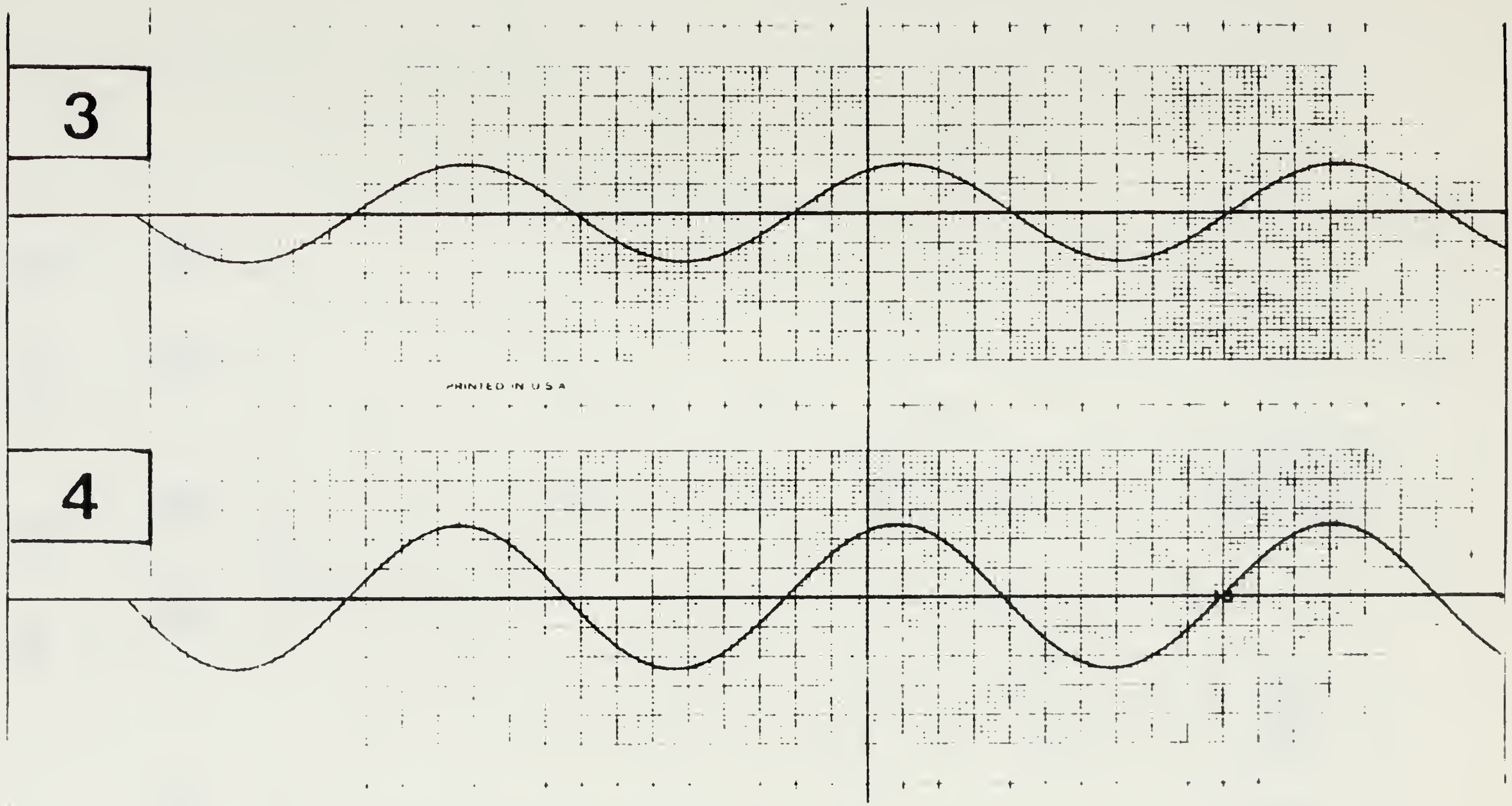


Figure 6. Yaw (3) and Pitch (4) Indicator functional voltage input plots

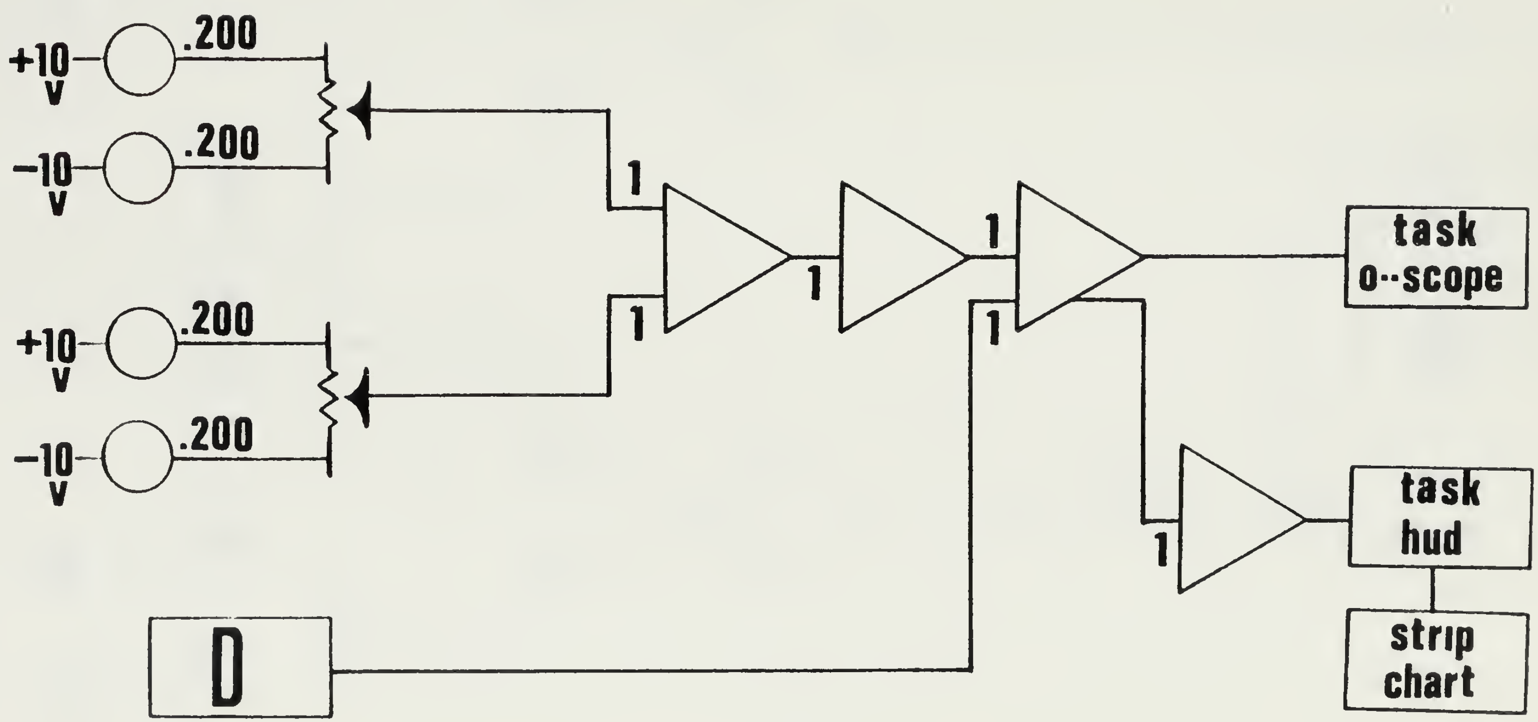


Figure 7. Logic diagram for side-slip display

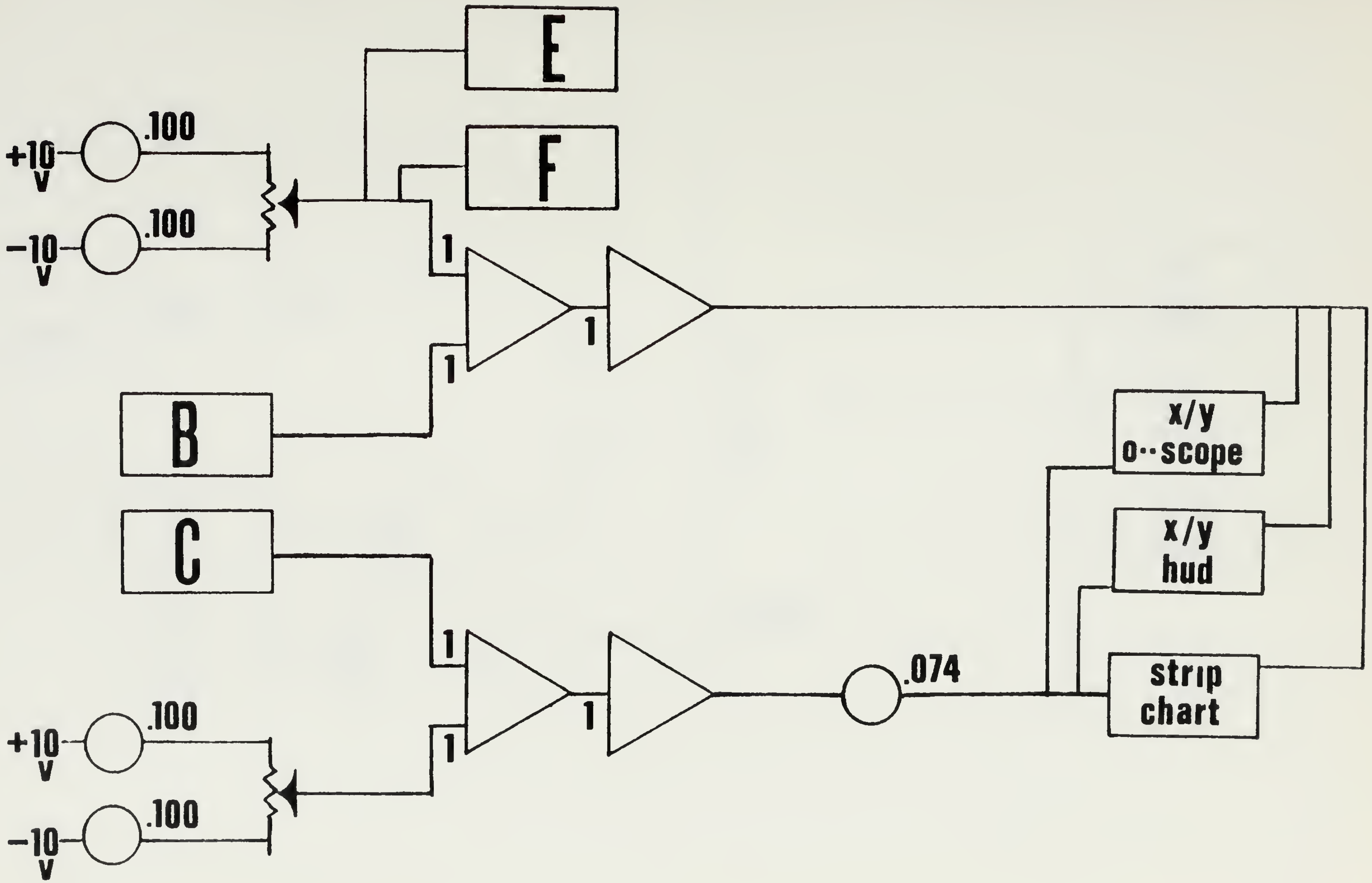


Figure 8. Logic diagram for yaw and pitch display

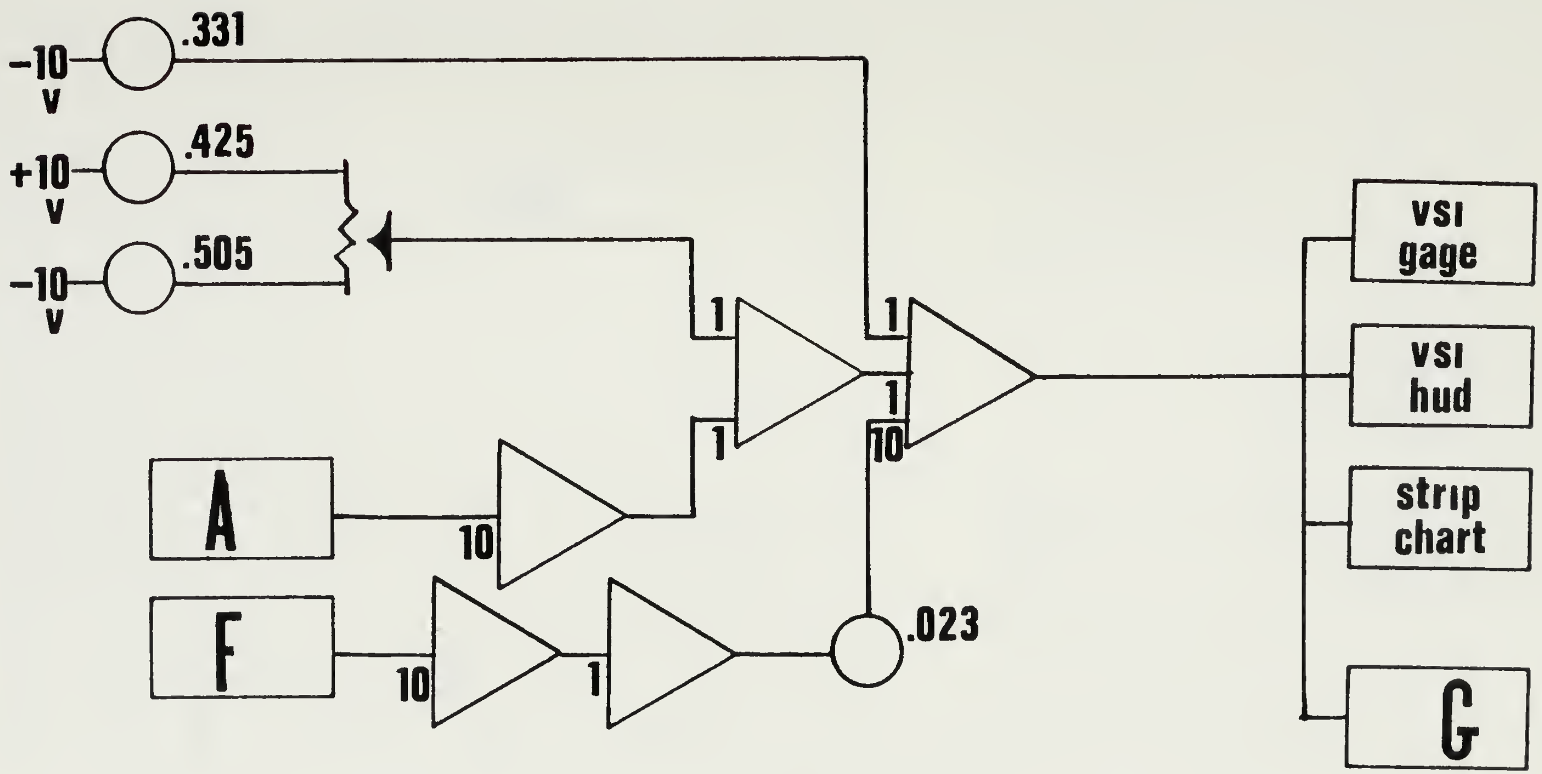


Figure 9. Logic diagram for vertical speed display

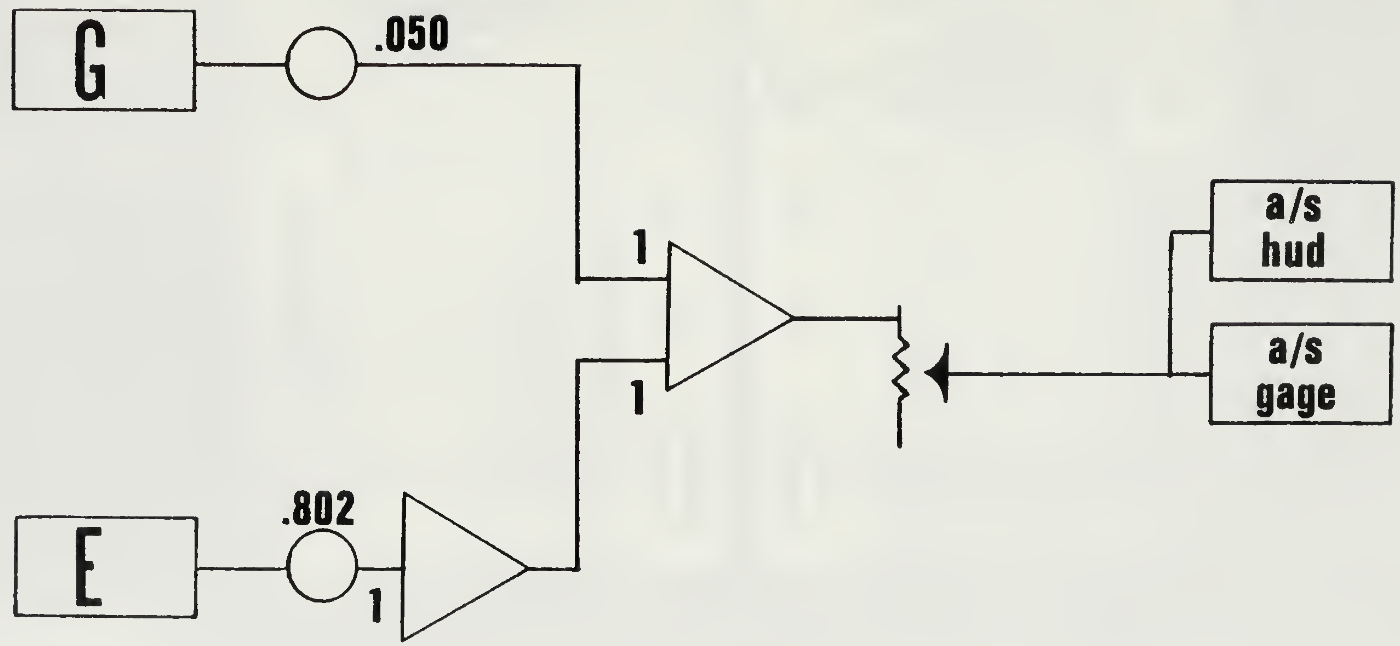


Figure 10. Logic diagram for airspeed display

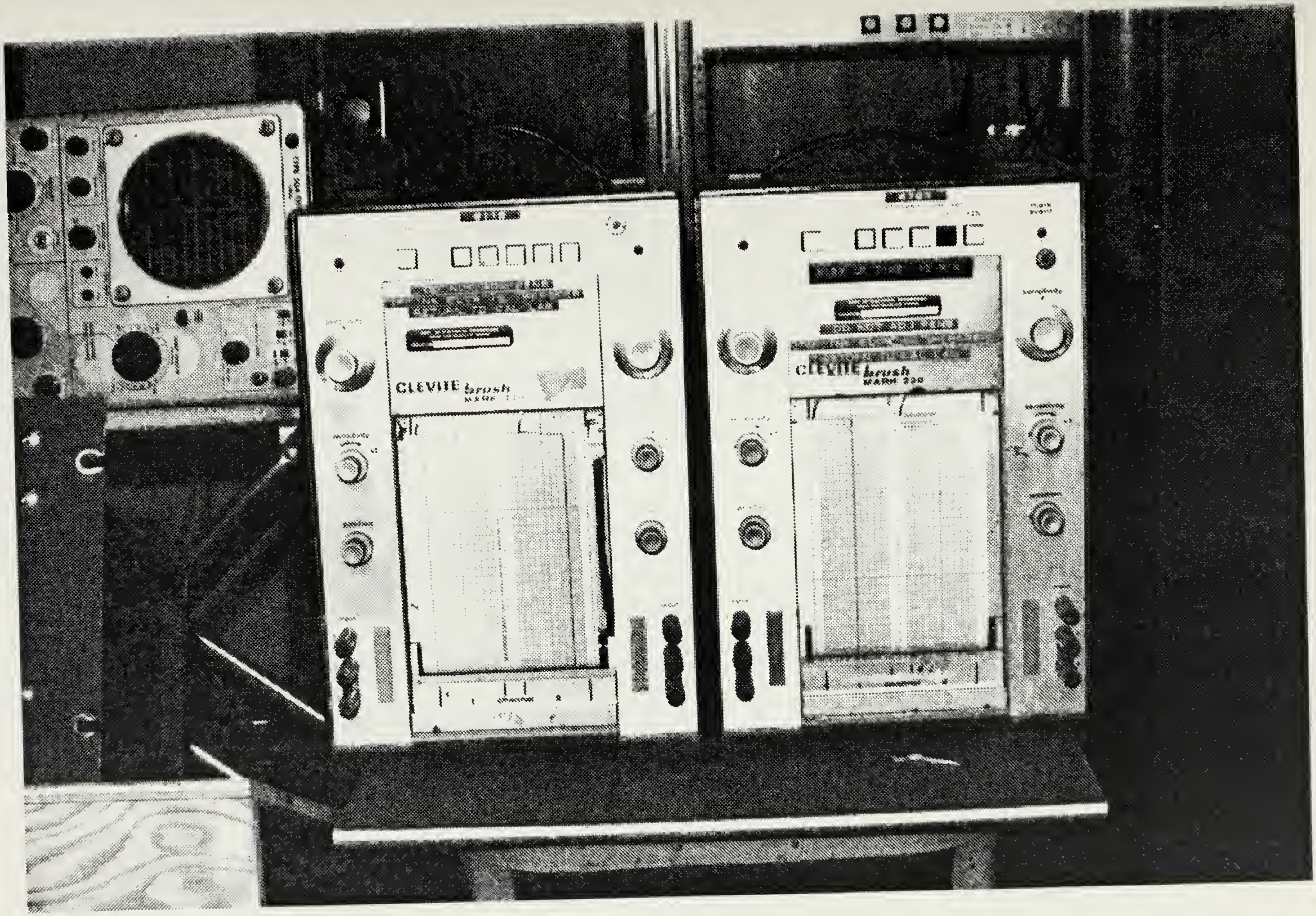


Figure 11. Strip chart recorders

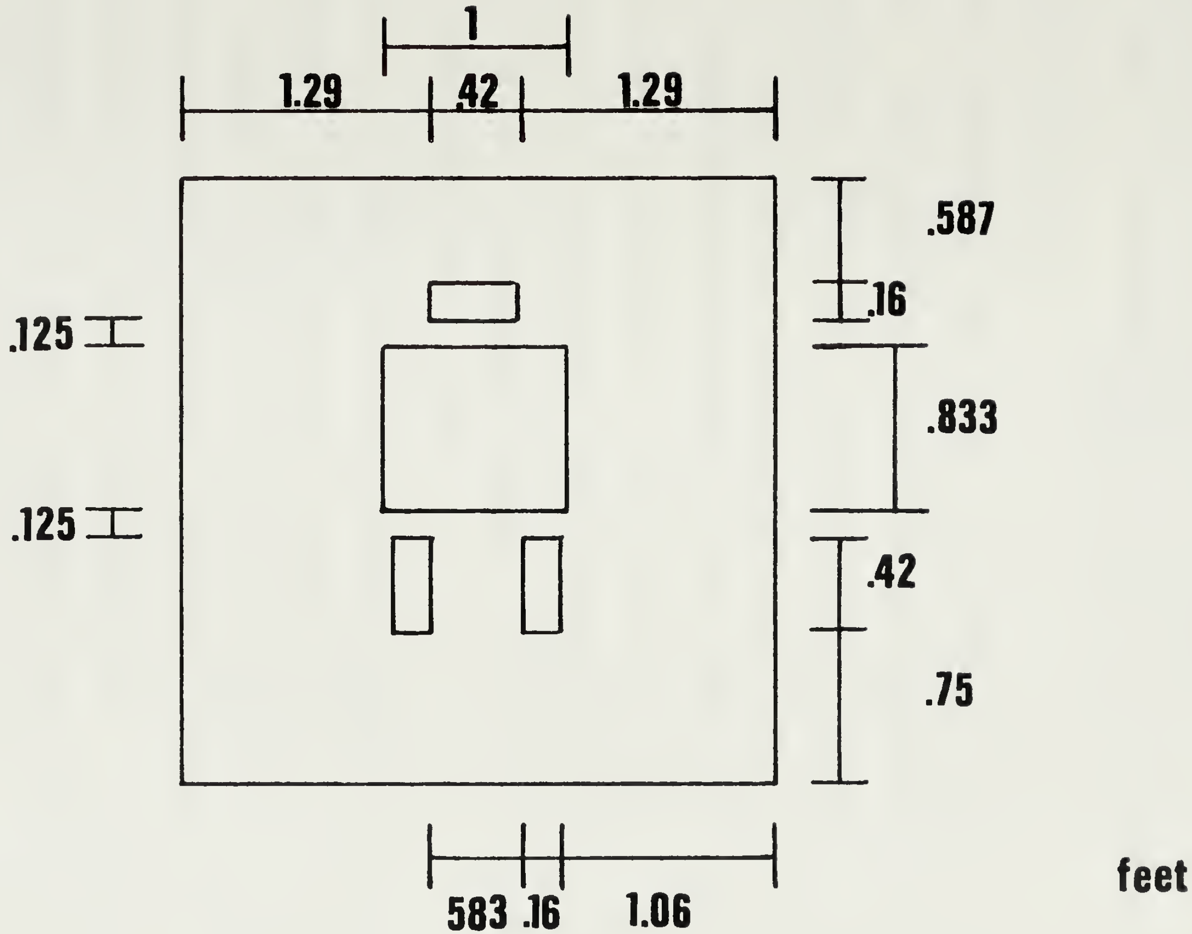


Figure 12. Head-up display face plate parameters

flight, and constant airspeed. A small airplane was fixed to the plotter's tracking arm as a reference with-respect-to the simulated horizon. In addition, pitch lines and a rectangular box (i.e., the area of maximum airplane travel) were taped to the base plate of the plotter (Figure 13).

E. DATA COLLECTION

The subjects of the evaluation were helicopter rated pilots. Their scope of experience encompassed the following helicopters: UH-1, AH-1, SH-2F, SH-3G, and UH-46. All of the evaluated pilots were currently enrolled in the Aeronautical Engineering curriculum and had not flown a helicopter in at least eight months. Each pilot had logged a minimum of 600 hours of helicopter time and none had prior flight experience with a head-up display. All were qualified helicopter instrument pilots.

Each individual received a taped briefing and five minutes of practice flight time prior to his flight. The flight brief explained the instrumentation, the head-up display symbology, control movements with their corresponding gage response, and the nature of the evaluation. Cyclic position was adjusted by the pilot. The gages and head-up display were centered to match the cyclic's position. Finally, the strip charts were baselined.

The three flights were nine minutes in duration. The initial minute was considered a grace/feeling-out period and subsequently not scored. The programmed inputs were identical

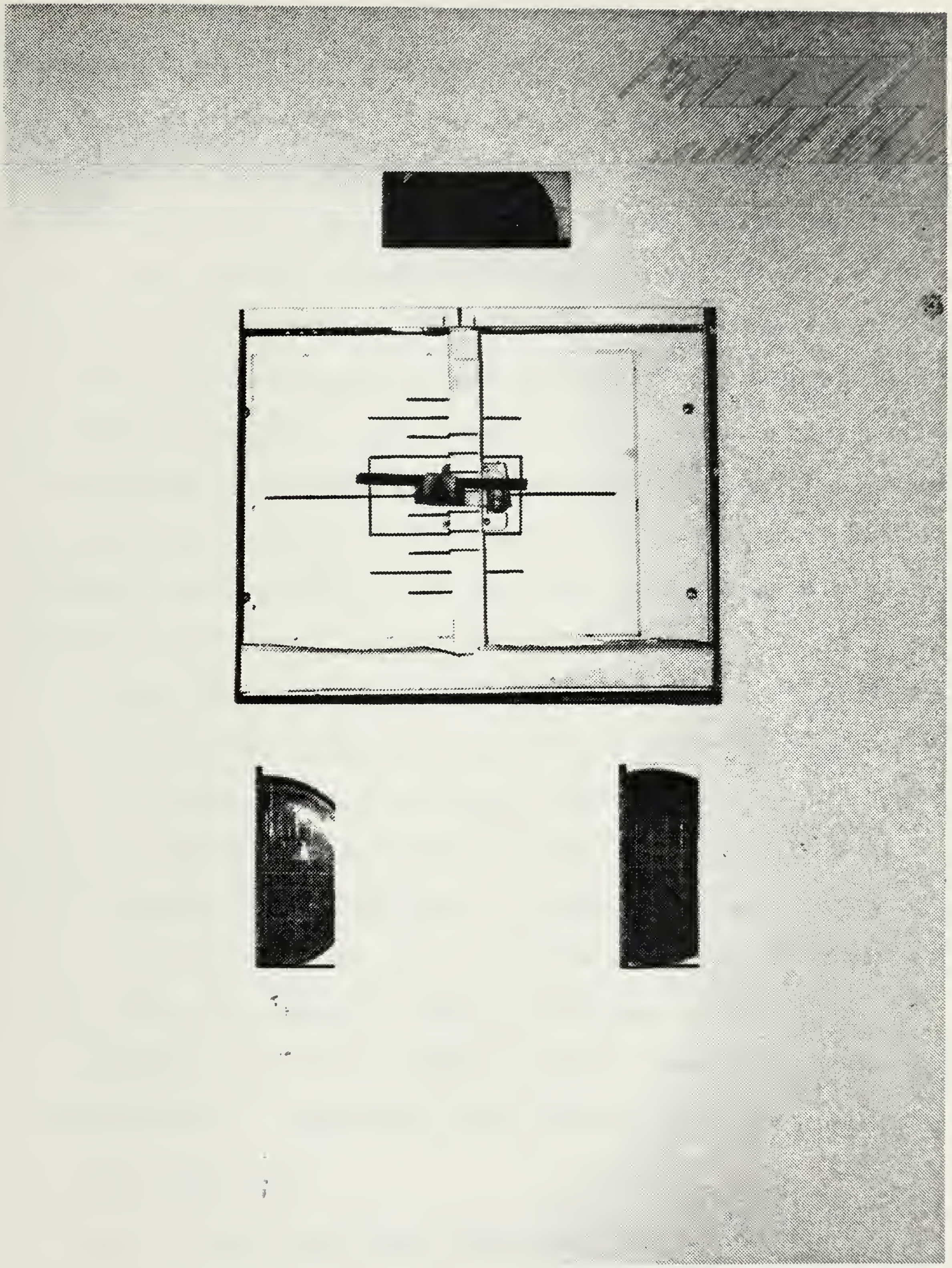


Figure 13. Head-up display attitude presentation (close-up)

for each flight. The first flight was a simulated instrument conditions flight with pilot reference to only the cockpit gages. This flight established a skill baseline level, unique to each pilot. His performance on the next two flights (using the head-up display only) were compared to this initial flight. The second flight had the monitor (i.e., the simulated head-up display) placed in the 12 o'-clock position on top of the cockpit instrument panel. This is the traditional position for the front, windscreen head-up projection. The monitor was placed at a 40 degree angle to the right of the pilot during the third flight. In this configuration it was hoped to learn if any orientation problems would surface since the pilot was constantly flying with his head turned to one side.

As previously mentioned, strip chart recorders graphically plotted the pilot's collective, cyclic, and rudder inputs used to correct for the voltage functions inputed by the analog computer. By measuring the percentage of time the pilot's response was outside of a zone considered representative of proper control, an evaluation of the pilot's ability to fly using the head-up display was made.

Following the flight testing period each pilot completed a questionnaire (Appendix A and Figure 14).

F. DATA REDUCTION

The raw data from each flight was in the form of the four strip chart plots. One set of four plots per flight. Each

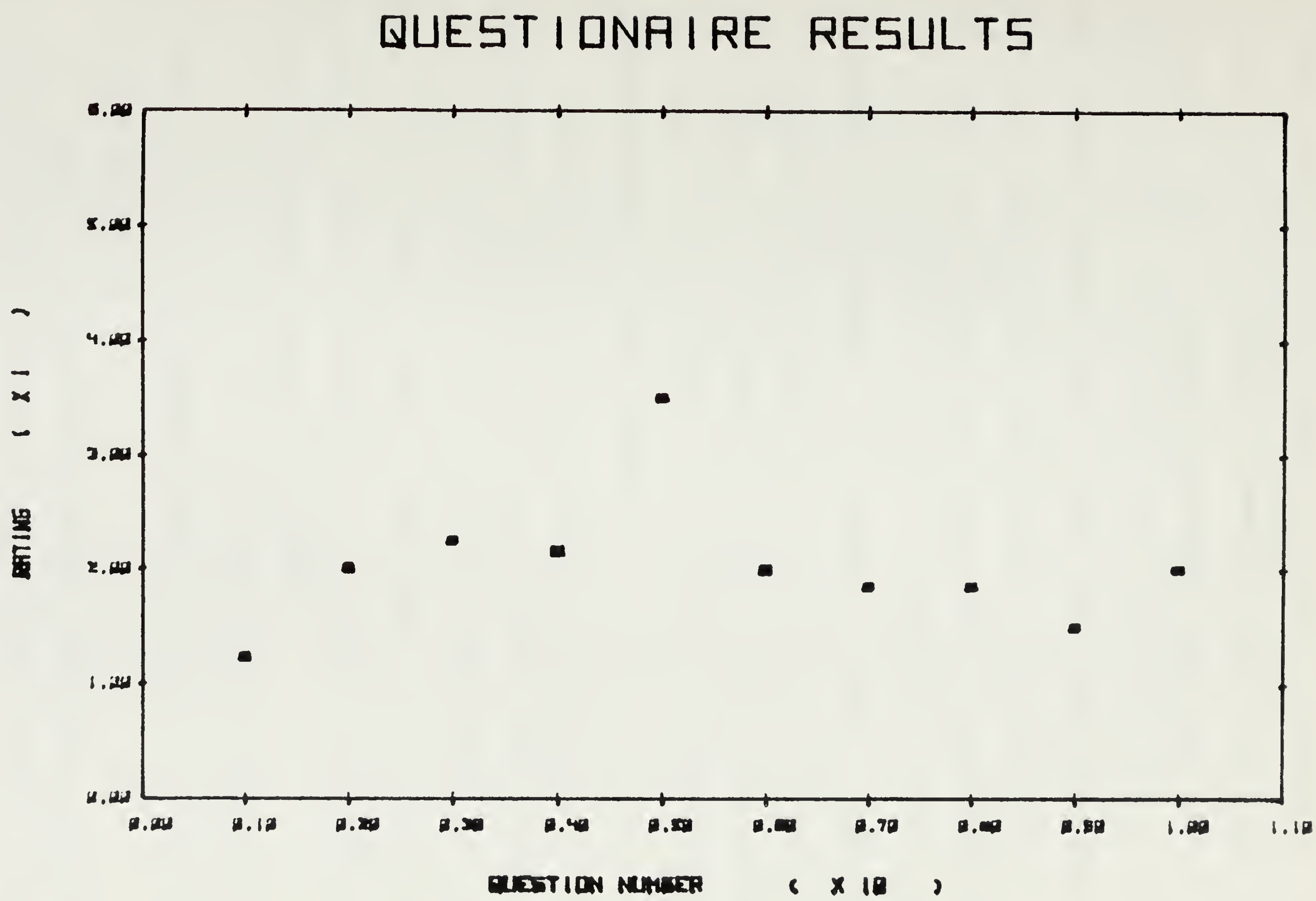


Figure 14. Questionnaire results

strip chart plot was the summation plot of the pilot's control input and the analog computer's voltage function. Chart 1 was the sine wave summation plus the rudder pedal inputs. Chart 2 was one programmed sine wave plus the collective input. Chart 3 was one programmed sine wave plus the lateral cyclic input. Chart 4 was one programmed sine wave plus longitudinal cyclic input (Figures 15 and 16). The strip chart design was such that any pen deflection above or below the center position represented an over or under controlling condition. The degree of over or under control was measured by the distance of deflection from the center. The length of the deflection along the time axis represented the speed of the pilot's corrections or a measurement of his attentiveness or lack thereof.

In order to derive a meaningful measurement of the pilot's performance, the strip chart was divided into three zones on either side of the center position. The zones were numbered 1, 2 and 3 from the center out. Zone 1 was labeled excellent control, Zone 2 fair control, and Zone 3 poor control. These zones were scaled as follows:

(1) Zone 1 was a full indicator needle width deflection either side of its neutral position (neutral defined as its initial position).

(2) Zone 2 was one and one-half indicator needle width deflection either side of center, minus the area of Zone one.

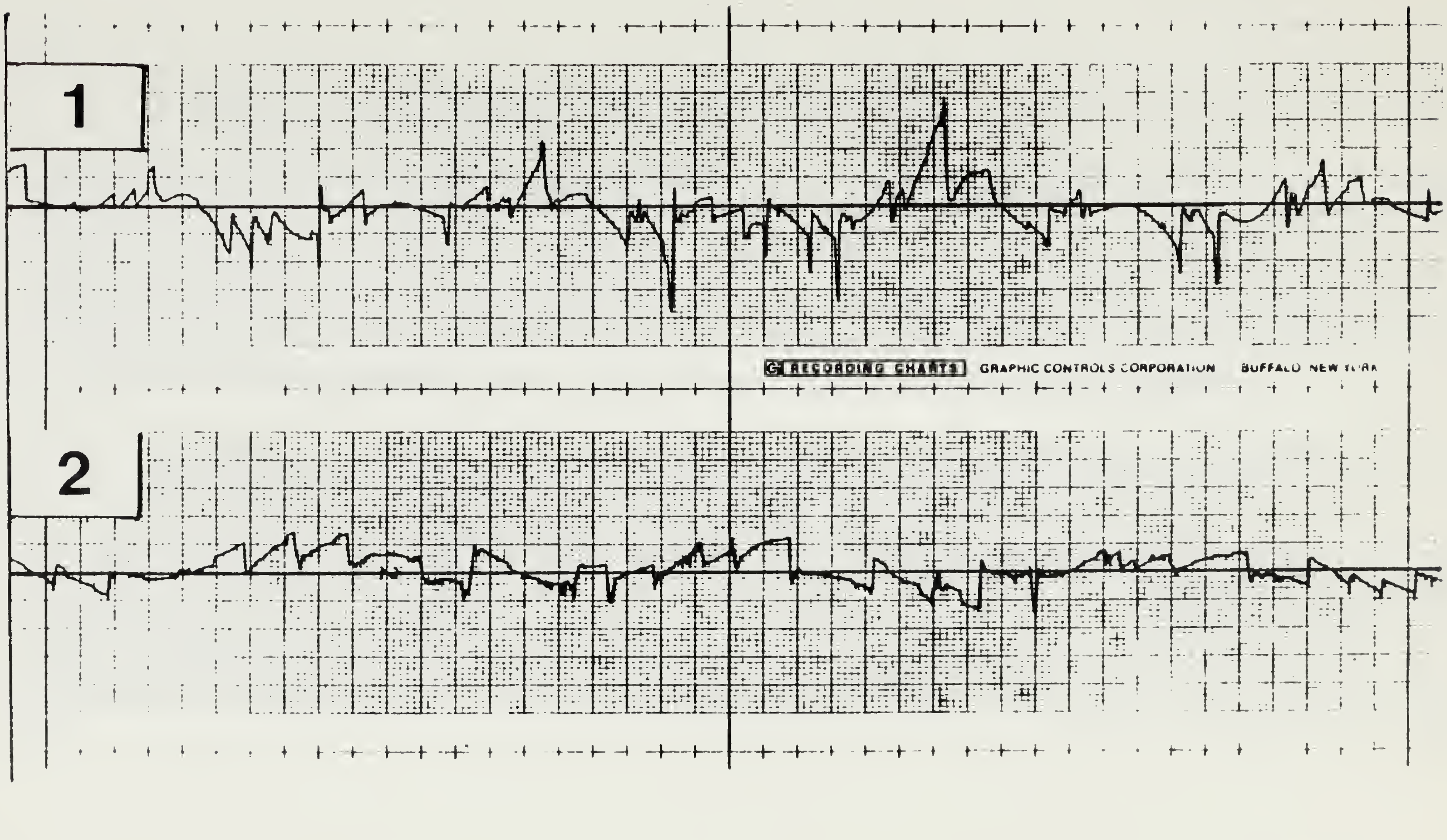


Figure 15. Pilot performance strip chart Side-slip (1) and Vertical Speed Control (2)

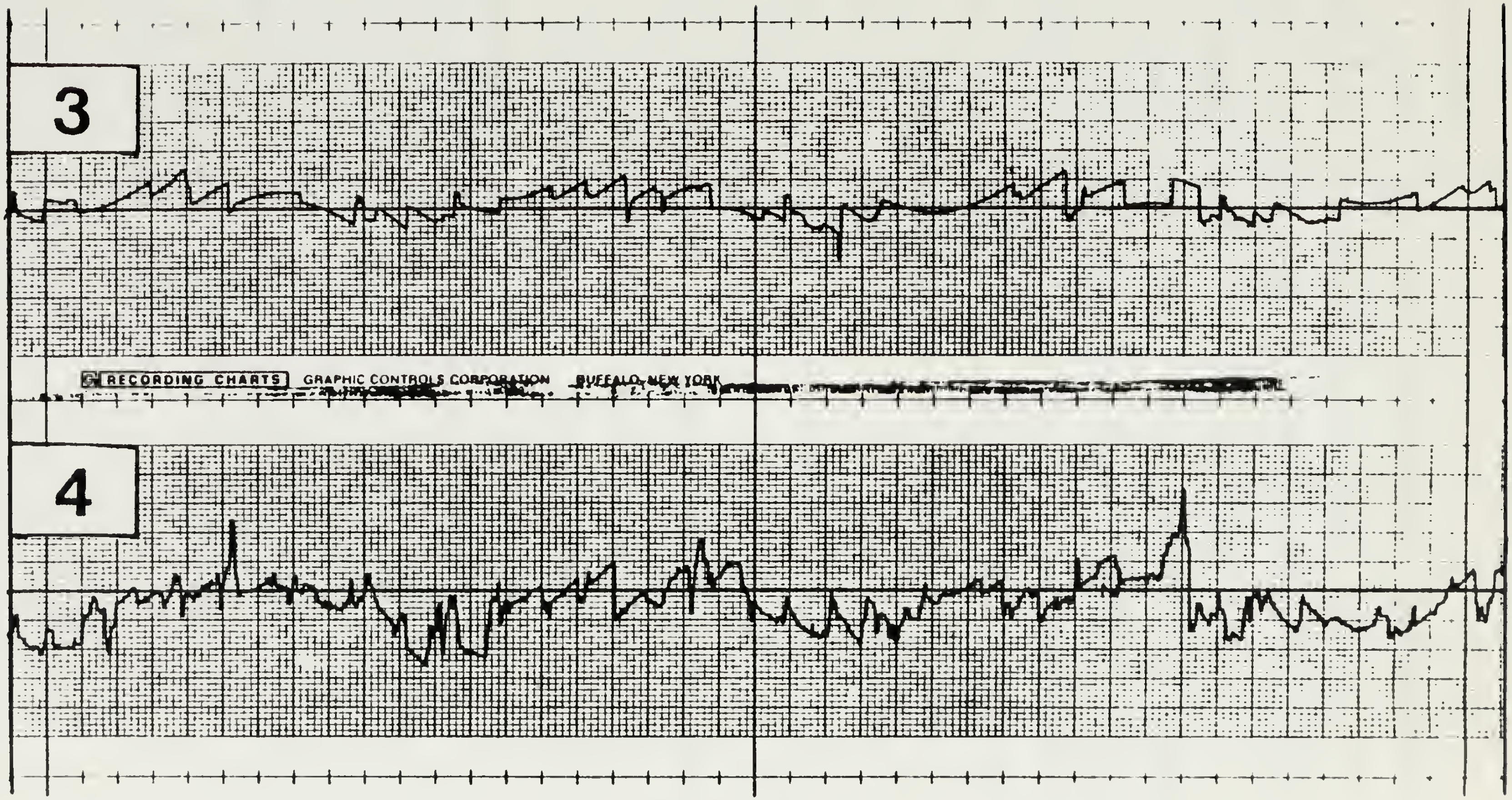


Figure 16. Pilot performance strip chart Yaw (3) and Pitch Control (4)

(3) Zone 3 was the area outside of Zone two on either side of center.

A full needle width was a large enough deflection, due to the thickness of the indicators, that a pilot should have been able to observe this movement and make a proper control input thereby correcting his attitude.

A clear plastic grid overlay was made to measure the amount of time the pilot was flying in each of the three performance zones (Figures 17-19). Because the physical sizes of the indicators on the head-up display were smaller than the cockpit gages, the widths of the zones on the grid overlays were wider in order to preserve the scaling mentioned in the conception of the performance zones. Each pilot's strip charts were reduced to digital form then an overall performance table was generated from the individuals data (Table I). Since flying time in performance Zone one represented excellent control, it was used as the grading criterion for each pilot. A plot was made of each pilot's time in Zone one for each control input and then an average of all the pilots for each control input was recorded (Figures 20-23). Prior to averaging, the circled points on the plots were discarded due to the pilot's admittance of not maintaining a scan on the gage or display that required the respective control input in question.

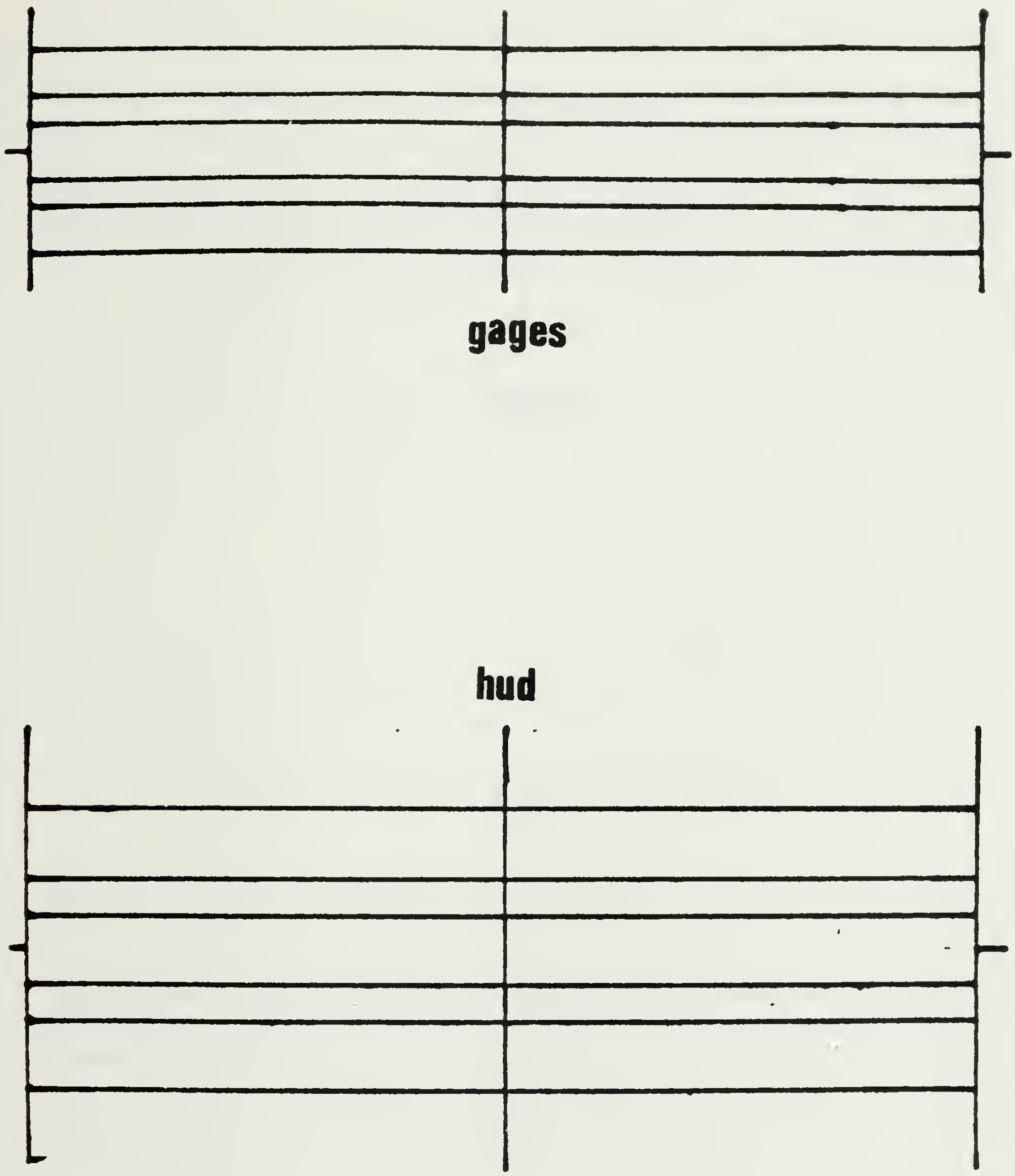


Figure 17. Zone grids: Side-slip

gages

hud

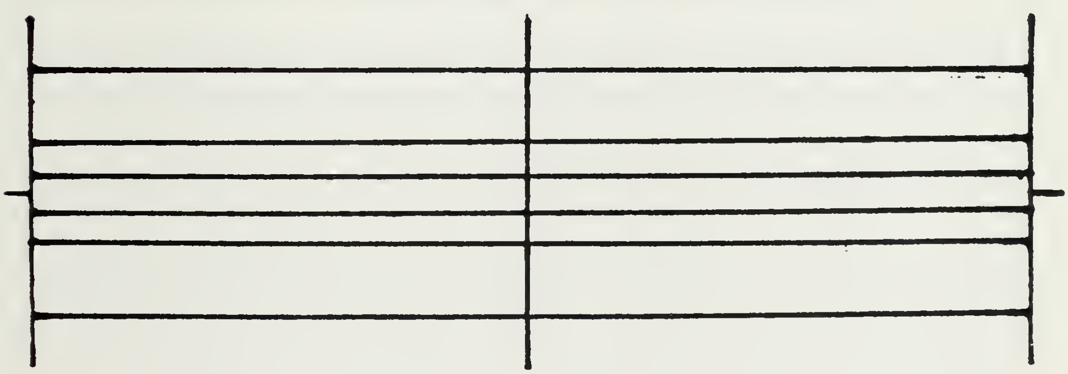


Figure 18. Zone grids: Vertical Speed

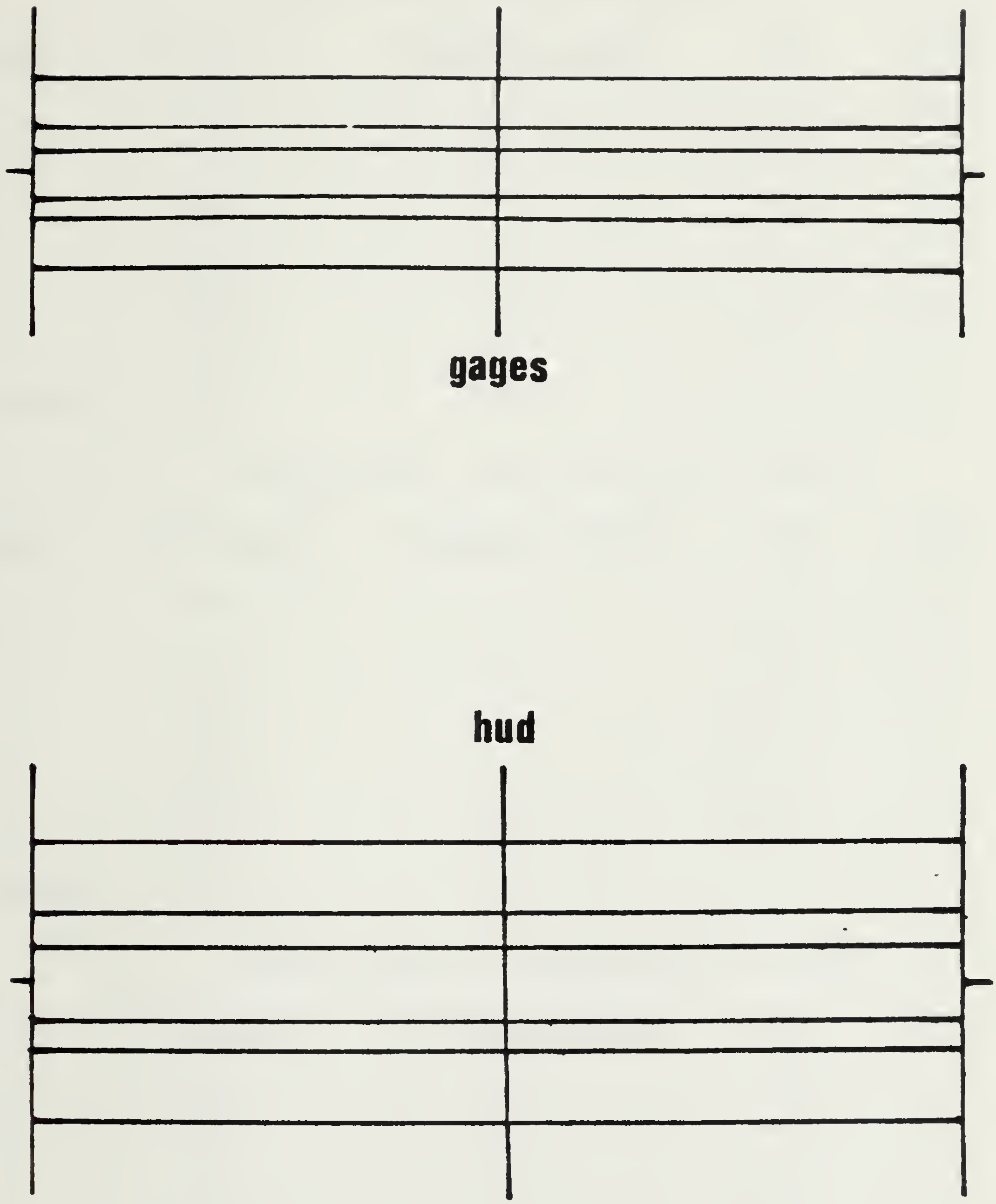


Figure 19. Zone grdis: Yaw and Pitch

TABLE I

Individual Pilot Performance: Zone One

Flight One: Instrument Scan

PILOT	SIDE-SLIP	VERTICAL SPEED	YAW	PITCH
1	86.3*	9.4	99.4	98.6
2	79.4	80.0	93.5	91.9
3	86.9	75.7	97.7	93.8
4	69.4	43.8	99.2	96.5
5	99.0	48.6	98.3	82.0
6	81.0	80.8	99.2	97.7
AVERAGE	83.7	56.4	97.9	93.4

Flight Two: Hud Scan (12 o'clock)

PILOT	SIDE-SLIP	VERTICAL SPEED	YAW	PITCH
1	97.1	37.5	98.2	84.4
2	87.0	77.0	99.4	96.0
3	91.7	57.3	98.6	64.5
4	79.4	44.7	100.0	93.1
5	91.4	41.7	99.4	88.8
6	95.6	74.5	100.0	88.5
AVERAGE	90.4	55.5	99.2	85.9

Flight Three: Hud Scan (2 o'clock)

PILOT	SIDE-SLIP	VERTICAL SPEED	YAW	PITCH
1	91.9	78.1	99.8	59.4
2	88.1	68.3	99.6	89.6
3	88.6	34.4	100.0	94.5
4	89.0	49.6	100.0	94.8
5	94.6	80.0	99.7	93.0
6	95.4	24.4	100.0	91.0
AVERAGE	91.3	55.8	99.8	87.0

*Percentage of time on Zone one

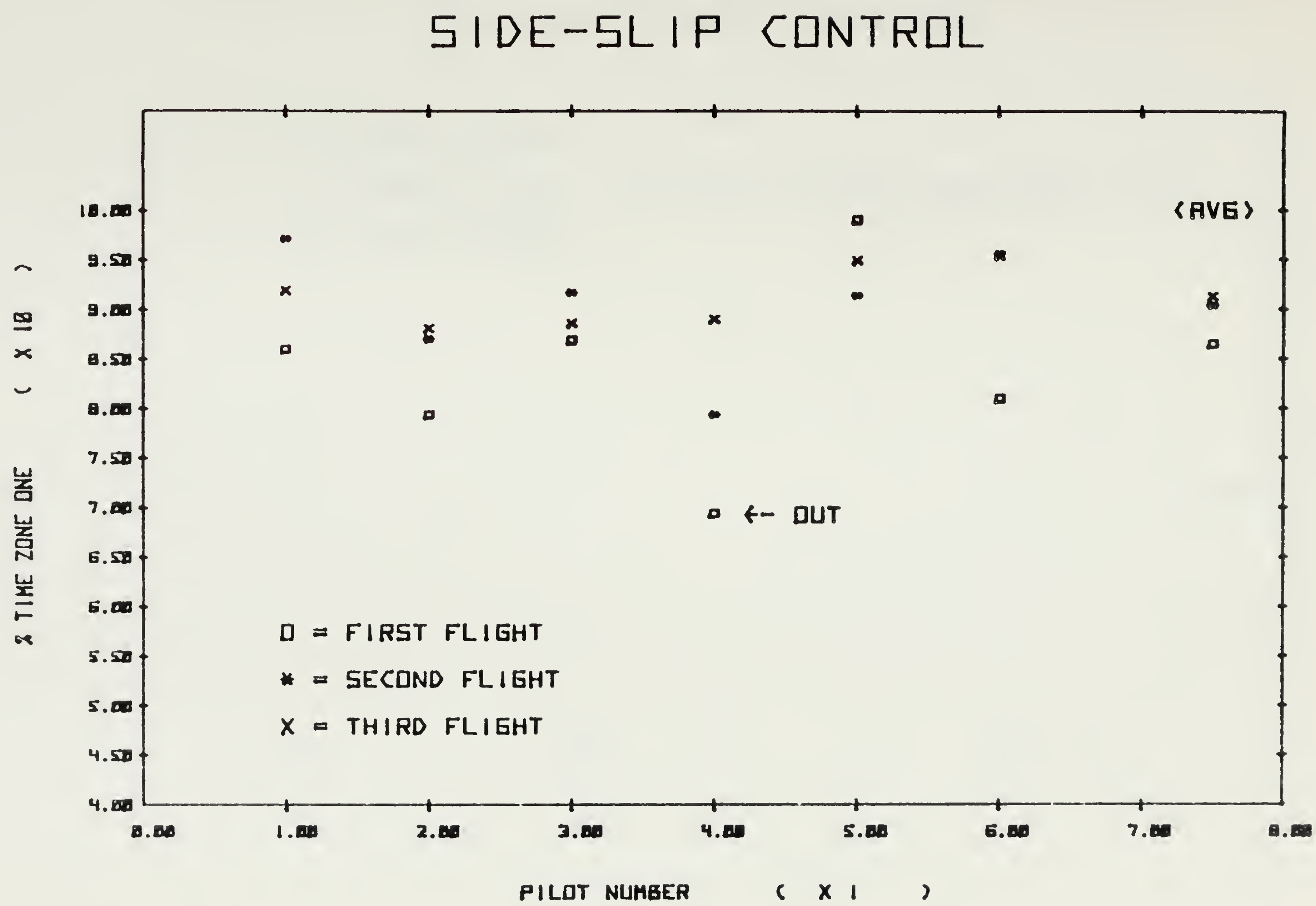


Figure 20. Pilot performance plot: Side-slip Control

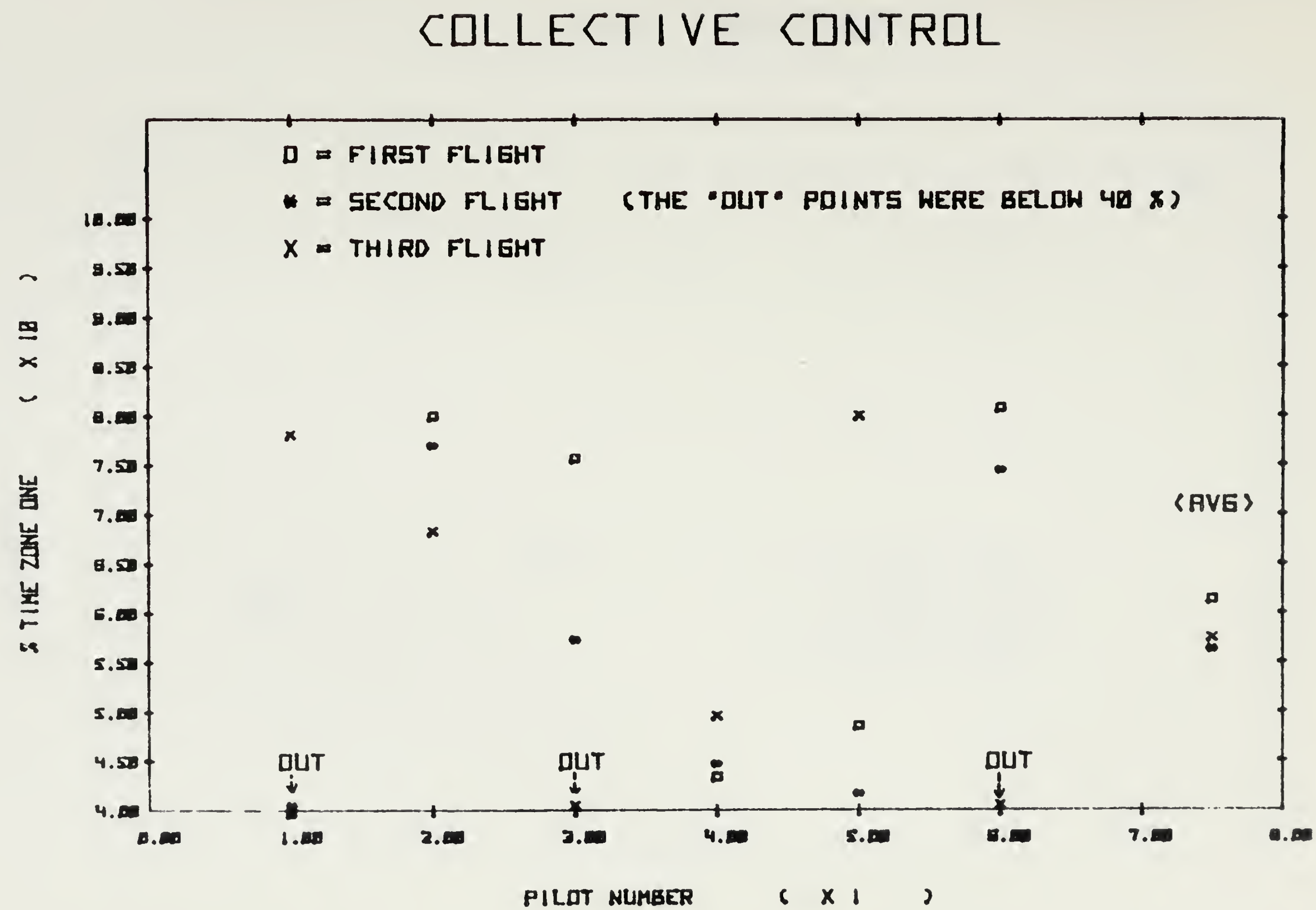


Figure 21. Pilot performance plot: Vertical Speed Control

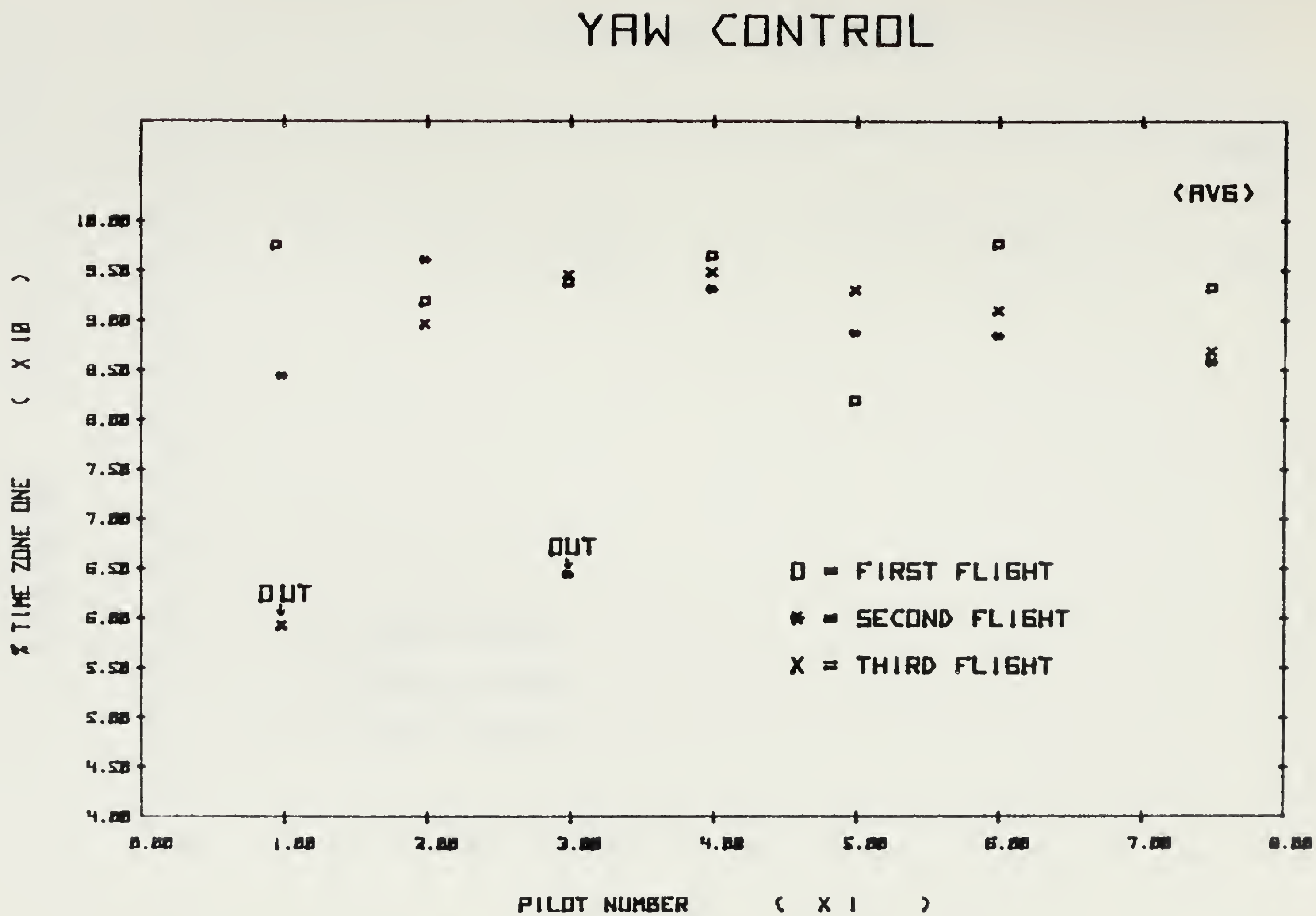


Figure 22. Pilot performance plot: Yaw Control

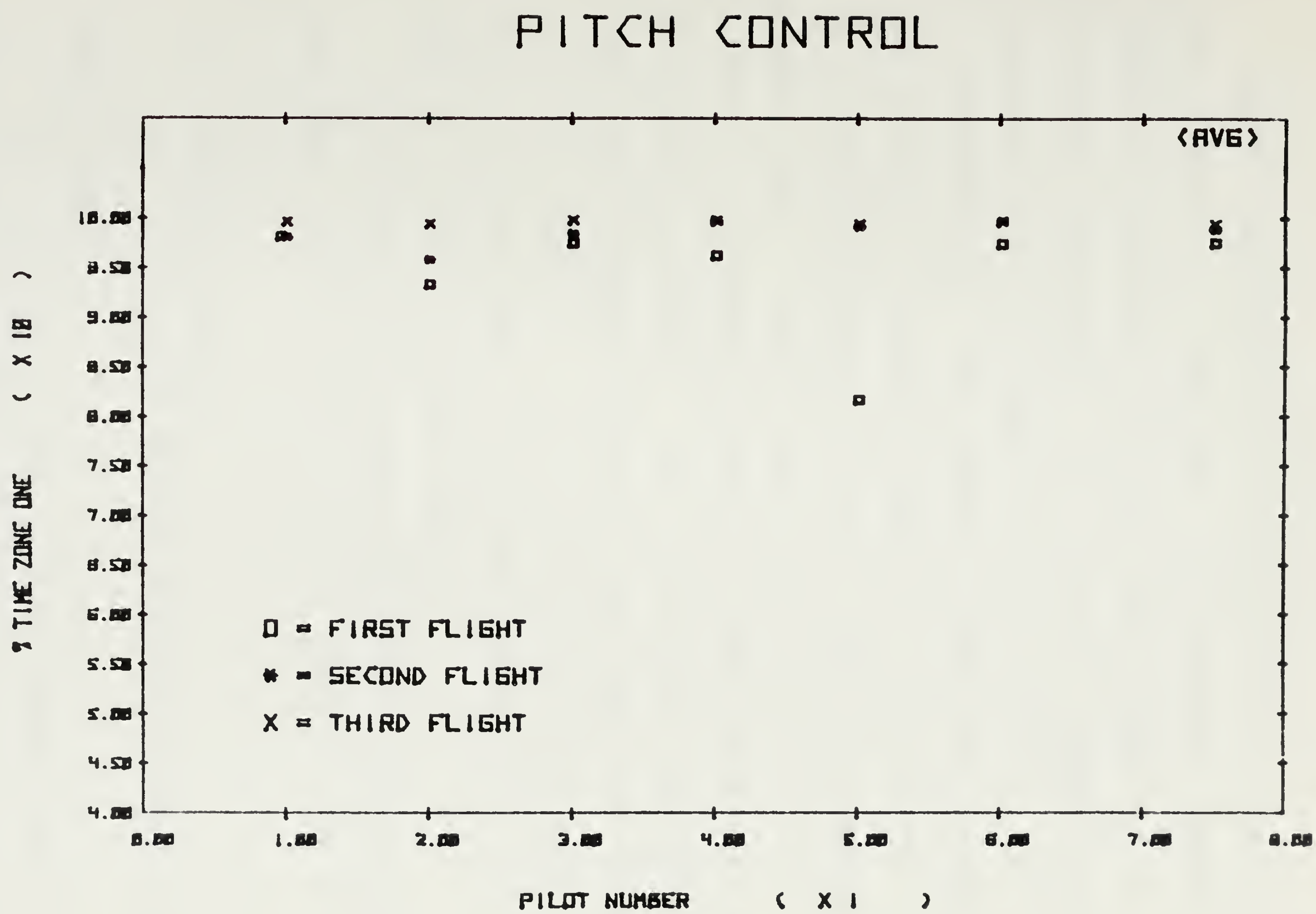


Figure 23. Pilot performance plot: Pitch Control

III. CONCLUSIONS

Overall performance and simulation by the generic helicopter cockpit was very good. Pilot negative comments were limited to stiffness in the left rudder pedal and poor seat adjustment capabilities. All the pilots agreed that the simulated cockpit instrumentation was adequate, easily read and comprehensible. The head-up display and its symbology also received a favorable reception. The need for a better way to display changes in vertical speed fluctuations was a possible area of needed improvement, as pointed out by the overall low performance average for this particular section on the head-up display. Also, four pilots completely dropped this display section from their total scan while flying on the head-up display. Pilot reaction to flying with a head-up display was very good. They felt it would be an advantageous addition to any helicopter cockpit.

By plotting the time each pilot spent flying in Zone one (excellent flight control) and then averaging the results, it was shown:

(1) Side-slip control:

(A) Five pilots improved their performance using the head-up display.

(B) The one pilot who did not improve was only out of Zone one six to eight percent of the time more using the head-up display.

(C) Overall aveage showed an improvement of seven percent for flight using the head-up display.

(2) Collective control:

(A) Four points were discarded from the analysis because the pilot in each case did not maintain the vertical speed indicator in his scan pattern while flying.

(B) Three pilots improved their controllability using the head-up display.

(C) Overall average showed no improvement or degradation for flight using the head-up display.

(3) Pitch control:

(A) All pilots flew near perfect control.

(B) No improvement or degradation was noted using the head-up display.

(4) Yaw control:

(A) Two data points were discarded because the pilots failed to maintain the indicator into their scan pattern while flying with reference to the head-up display.

(B) Only one pilot showed any noteworthy improvement in his control using the head-up display.

(C) Overall average showed a six to seven percent reduction in pilot performance using the head-up display indicator for yaw control.

The graphical data plots show where the individual pilots fell out on each flight (Figures 20-23). The average helicopter pilot's flight performance using the head-up display

was within four to seven percentage points of his performance using only cockpit instrumentation.

Placement of the head-up display to the right of the pilot resulted in higher performance than when it was directly in front. Two factors could account for this: First, the third flight was with the display to the side and therefore consideration must be made to the fact that the pilot has had eighteen minutes of prior experience with the cockpit. By then he had learned the cockpit, was much smoother with his control inputs and more attentive with his scan. Second, for most of the pilots, scanning to the side is the dominant position for them under the highest workload conditions when they are operating an actual helicopter.

Since the pilot's average performance using the head-up display was equal to or a little better than using a cockpit instrument scan, it is suggested that a head-up display can be successfully introduced into a helicopter cockpit without greatly affecting the pilot's flying performance. With this in mind, it is recommended that the head-up display be used but, perhaps better as a primary tactical display with the added capabilities to be programmed by the pilot with specific flight parameter indicators of his choosing.

APPENDIX A

SAMPLE QUESTIONNAIRE

Rate numbers 1 through 10 using the scale listed below.

1	2	3	4	5
EXCELLENT	GOOD	FAIR	POOR	UNSAT

------ (1) Mental attitude towards being used in this evaluation

------ (2) Physical feeling at the time of your evaluation

------ (3) Cyclic control movement

------ (4) Collective control movement

------ (5) Rudder control movement

------ (6) Cockpit instrumentation

------ (7) Head-up display symbology

------ (8) Duration of the evaluation flights

------ (9) Ability to scan the head-up display

------(10) Ability to concentrate on the flight

Comment on the following:

(1) Your opinion of flying with a head-up display

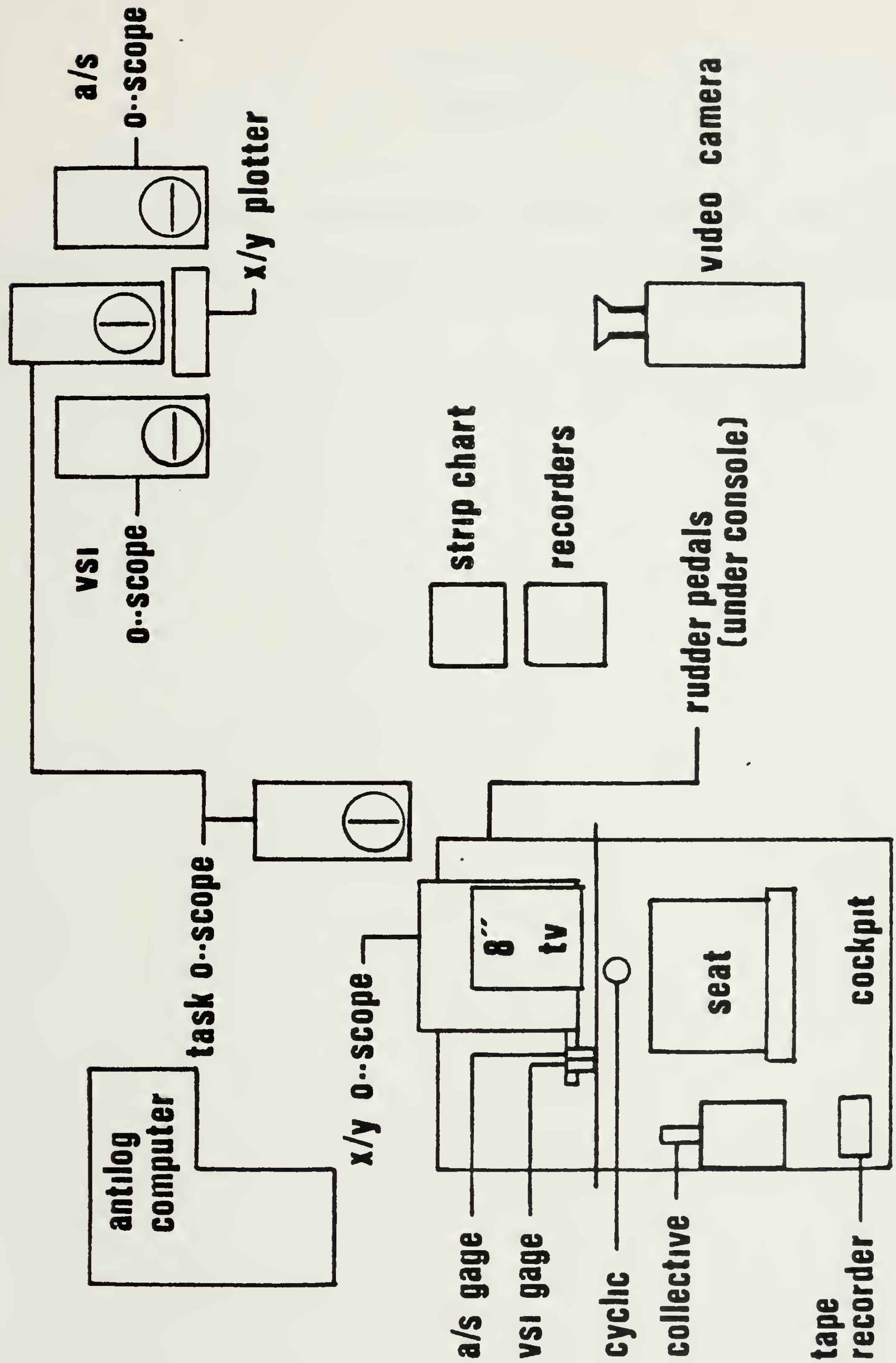
(2) How would you improve the head-up display's symbology?

(3) How could this thesis project be improved?

APPENDIX B

EVALUATION FACILITIES

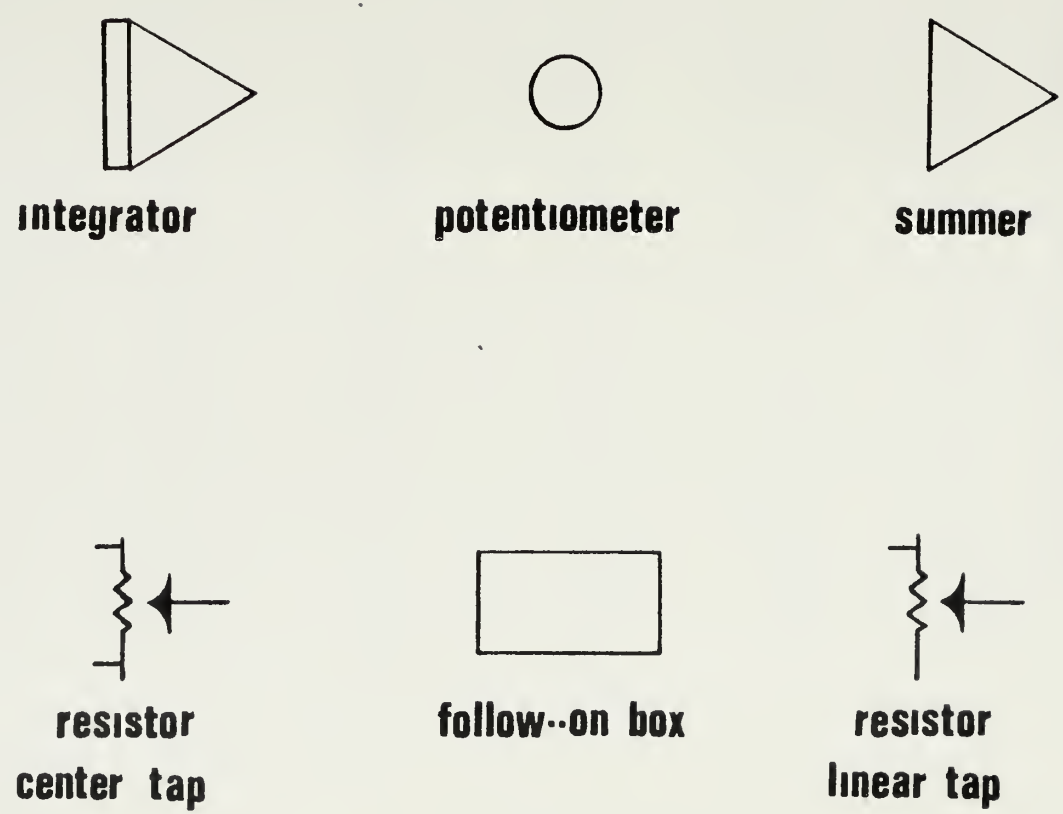
The following appendix is a layout of the facility used in the evaluation phase. This area was located in Halligan Hall, Room 024, Naval Postgraduate School, Monterey, California.


a/s
o-scope
x/y plotter
vsi
o-scope
video camera
strip chart
recorders
rudder pedals
(under console)
task o-scope
antilog
computer
x/y o-scope
8"
tv
seat
cockpit
a/s gage
vsi gage
cyclic
collective
tape
recorder

APPENDIX C

SYMBOLS

This appendix includes the symbols used in the logic diagrams of the electrical circuitry developed for this project.


integrator
potentiometer
summer
resistor
center tap
follow-on box
resistor
linear tap

APPENDIX D

BLOCK DEFINITION

This appendix contains a list and explanation of each lettered box used in the logic diagrams.

A FUNCTIONAL INPUT TO VERTICAL SPEED INDICATOR

B FUNCTIONAL INPUT TO YAW INDICATOR

C FUNCTIONAL INPUT TO PITCH INDICATOR

D FUNCTIONAL INPUT TO SIDE-SLIP INDICATOR

E PITCH FEEDBACK TO AIRSPEED INDICATOR

F PITCH FEEDBACK TO VERTICAL SPEED INDICATOR

G VERTICAL SPEED FEEDBACK TO AIRSPEED INDICATOR

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Stichter
Evaluation of helicopter pilot's attitude control using a simulated head-up display in a simulated helicopter cockpit.